DOCUMENT RESUME

ED 322 401 CE 055 595

TITLE Resources in Technology 6.
INSTITUTION International Technology Education Association, Reston, VA.
PUB DATE 89
NOTE 69p.; For related volumes, see CE 055 590-594.
AVAILABLE FROM International Technology Education Association, 1914 Association Drive, Reston, VA 22091-1502 ($6.50 members, $7.50 nonmembers; six-volume set: $35.00 members, $37.50 nonmembers).
PUB TYPE Collected Works - General (020) -- Guides - Classroom Use - Materials (For Learner) (051)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS *Agricultural Production; *Artificial Intelligence; Construction (Process); *Creativity; Futures (of Society); Industrial Arts; Metals; Postsecondary Education; Science and Society; Secondary Education; *Technological Advancement; Technological Literacy; *Transportation
IDENTIFIERS *Biotechnology; *Polymer Chemistry

ABSTRACT

This document--intended to help technology education teachers plan their classroom curriculum for secondary school and college students--contains units on creativity, artificial intelligence, biotechnology, polymeric materials, manufacturing in space, metallic materials, intermodal transportation, and food production. The sociocultural impact of each of those topics and its relationship to the common elements of technological systems are covered in each unit. Units also typically include narrative information, line illustrations, photographs, a glossary of technical terms, a constructional activity, examples of how math and science can be used to support the students' constructional activities and provide the motivation for students to make the connections between technical education and math and science, a student quiz, possible student outcomes, and references. (CML)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED322401

Resources in Technology

6

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

J. Fulton

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

CE055595

International Technology Education Association

BEST COPY AVAILABLE

1 Creativity—Tool for the Imagination
9 Introduction to Artificial Intelligence
17 Biotechnology
25 Polymeric Materials
33 Manufacturing in Space
41 Metallic Materials
49 Intermodal Transportation
57 Food Production

Contributing Authors
Tidewater Technology Associates
Members:
John M. Ritz
Walter F. Deal, III
W. Fred Hadley
James A. Jacobs
Thomas A. Kildruff
K. George Skena

Note: These activities may be reproduced without permission for use in the classroom.
© 1989, International Technology Education Association

INTERNATIONAL TECHNOLOGY EDUCATION ASSOCIATION

Resources in Technology

Creativity Tool for the Imagination

Creativity is the resource that we all draw upon to understand and build our world. How can we learn to be more creative? A truly creative person can become a resource themselves in answering this question. Read this article and explore the ways to nurture your own creative talents.

Each of us is endowed at birth with natural wealth—with eyes that see, hands that reach, and an intense curiosity. As young children we ask "Why?" because we have to find out about this surprising world around us.

Some people seem to be able to maintain this childlike state of wonder and use it for creative ends. How do they do it?

People who are creative possess certain traits. These include ambitiousness, perseverance, enthusiasm, energy, knowledge, and thinking. A creative person is not fearful of trying something new. He/she works hard and tries to get the job done. The creative person also perseveres. He or she keeps trying even when the results do not come easily. The creative person is enthusiastic. He or she believes in what they are doing and often comes up with new ideas. Also, the creative person has extra energy to keep trying. They are in good physical and mental health. The creative person also is knowledgeable; trying to seek new information and learn as much as they can. Finally, the creative person is a thinker. He/she uses his/her brain actively and enjoys doing it.

Thinking is a distinctly human characteristic. However, much of each human's thinking skills are wasted. Instead of using thinking as a resource and a skill, we tend to use it loosely and in a disorganized manner. The main difficulty of thinking is confusion. We try to accomplish too much too quickly. An important part of the thinking process involves developing the skill of creativity.

You might well question the term "skill" being applied to creativity. However, creativity involves a number of components that must be learned and used in a systematic manner. Additionally, creativity may be viewed as a nonscientific endeavor that is unique to individuals (a God-given endowment); that it usually occurs when a problem needs solving; that creativity can be a deeply enriching experience as it provides emotional, societal, and perhaps monetary rewards.

Our nation is just beginning to recognize the role of creativity in providing the competitive edge in the marketplace. This has been brought about by the competition for the creation and redesign of consumer products created by the Oriental nations of the world.

Contemporary Analysis

According to Bailey in *Disciplined Creativity*, creativity may be viewed from two distinct perspectives: the creative process and the creative product. The creative process involves certain prescribed steps that must be followed. On the other hand the creative product emphasizes the product that is to be produced.

Creative people share certain commonalties of the creative process. While there is no such thing as a recipe for creativity, there are some essential elements. These include:

- Challenging Assumptions
- Recognizing Patterns
- Seeing in New Ways
- Making Connections
- Taking Risks
- Taking Advantage of Chance
- Constructing Networks (Mind Crystals)

Challenging assumptions requires us to question what most people take as truth. In the time of Copernicus people thought that the earth was the center of the universe. They believed that the sun revolved around the earth. The courageous thinkers who defied these ideas were pushed aside and even had their lives threatened by their contemporaries. Later, they were respected and revered as great thinkers.

If we accept without ever questioning, we may never be aware of the alternatives that are unfolding before us. When students ask "Why?," they are frequently demanding explanations for what we accept without questioning. By asking questions they are practicing independent thinking not unlike what is practiced today by scientists and researchers (Figure 1).

The Wright Brothers defied the old belief that humans would never fly. They accomplished this feat by setting aside the notion that human flight required flapping wings like a bird. Instead, they focused on the soaring of large birds and thereby invented the three axes of flight (pitch, roll, and yaw) that remains unchanged until today.

They achieved success by continually questioning their own assumptions. No idea was held to be completely correct. All ideas were subject to testing and therefore to change (Figure 2).

The second element of the creative process—recognizing patterns—is detecting significant similarities or differences in ideas, occurrences, or physical phenomena. In searching for patterns we attempt to give form to the world around us. Distinguishing patterns in the unknown is a way of creating order out of chaos.

Basically, recognizing patterns provides quickness of recognition and hence quickness of reaction. Because one can recognize what one is looking for one can also explore the environment more efficiently. The study of patterns has allowed a number of scientists and creative thinkers to observe components of the problem from a new perspective. Gregor Mendel, the famed geneticist, studied the flowers of many generations of sweet pea flowers that were crossbred, before he made his discoveries about heredity.

Neptune was discovered in 1846 after the presence of a massive object was inferred from analysis of irregularities in the orbital motion (patterns) of Uranus, the next planet in toward the sun. The pattern, in this case, was irregular and not consistent. Attention to patterns led to the discovery of a new planet.

Seeing in new ways is seeing the commonplace with new perceptions, transforming the familiar to the uncharted, and the uncharted to the familiar.

As you look at this page, what do you see? You probably see it as letters and words to read. Now try looking at it as a graphic artist would—as a page of images and type. Or imagine that you are trying to decode a secret message or decipher a hidden or subliminal meaning. Now think of it as a collection of billions of carbon atoms. Any number of ways could be used to change the perspective we view this page. Each way has its own unique aspects and reveals a different form of the same page.

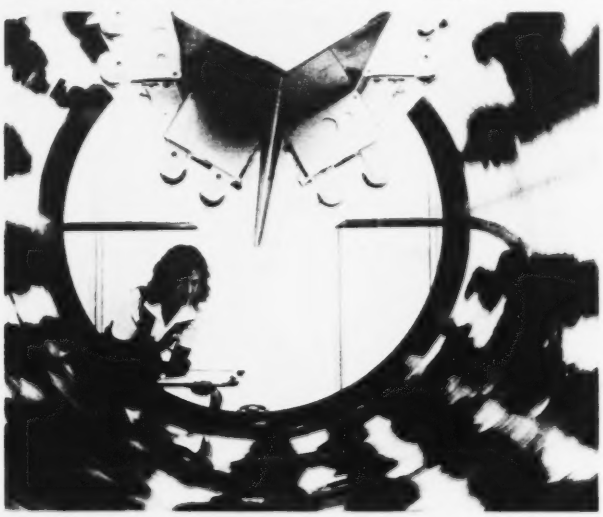


FIGURE 1
Giant whirling drum carries rows of lettuce in a spinning growth cycle.

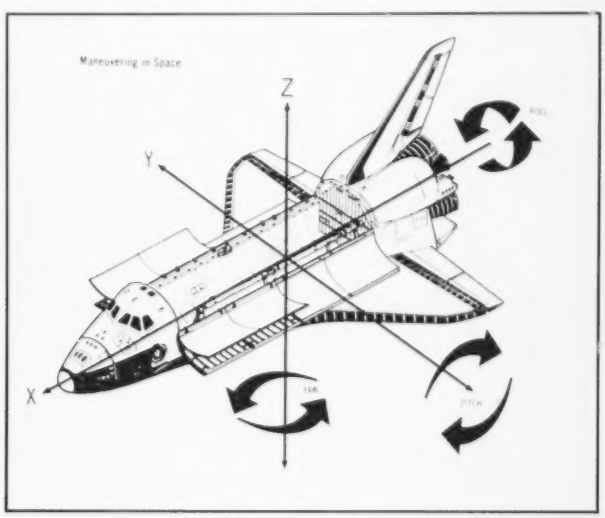


FIGURE 2
The principles of flight discovered by the Wright Brothers remained unchanged.

The late Andy Warhol took familiar objects like a soup can and made it into an art form. People viewing his art viewed the lowly soup can in a new and unusual manner. A creative perspective shoots out many images that we can associate with ideas that are already familiar to us.

Making connections is bringing together seemingly unrelated ideas, objects, or events in a way that leads to a new conception. Making connections can be like the moment when the author suddenly allows the link between two episodes or characters to become apparent.

Authors frequently use metaphor—a literary connection—to show how one idea relates to another. Phrases such as "flying like the wind", "sweet as the smell of new-mown hay", and "hard as a rock", are common, if overused, metaphors to convey a relationship between ideas.

Edward Jenner noticed that the deadly disfiguring disease of smallpox never afflicted milkmaids. By making the connection that the milkmaids became immune to the milder disease of cowpox, he derived the principle of vaccination. Louis Pasteur took the idea of vaccination and connected it to the microbes that were found in milk and developed the pasteurization process.

Finding connections in science and nature that may be applied to new technologies still occurs today. Sonar is based on the navigation system of bats using sound waves to detect objects in their path.

The cartoonist Rube Goldberg brought together ordinary objects in fanciful ways to construct wild inventions. His inventions spark the imagination and tickle our sense of humor (Figure 3 and 4).

Taking risks is daring to try new methods or ideas with little or no control over the outcome. Creative people must be willing to take risks. They are not afraid of being wrong, accepting criticism, or trying long shots.

Columbus, Magellan, Erickson, and other early explorers took great risks when they set out for long voyages to unknown lands and seas. In addition to the dangers from storms, illness, and mutinous crews, they believed they had a good chance of meeting up with a sea monster or other supernatural force. Instead of using the risks as a good excuse to cancel their voyages, these explorers sailed into the unknown (Figure 5).

Even people who have enjoyed past successes must take risks. Alexander Graham Bell risked new ventures even after his initial success with the tele-

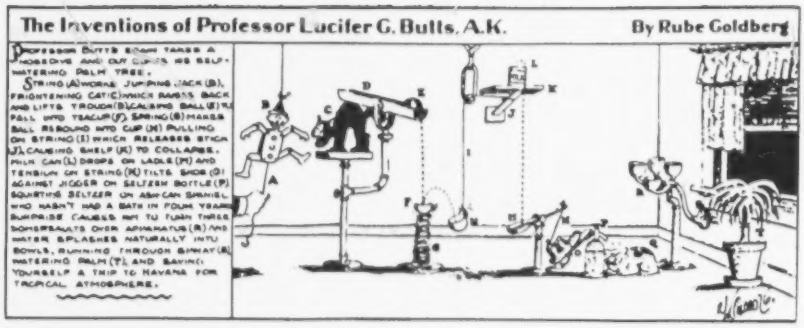


FIGURE 3
One of Rube Goldberg's designs.

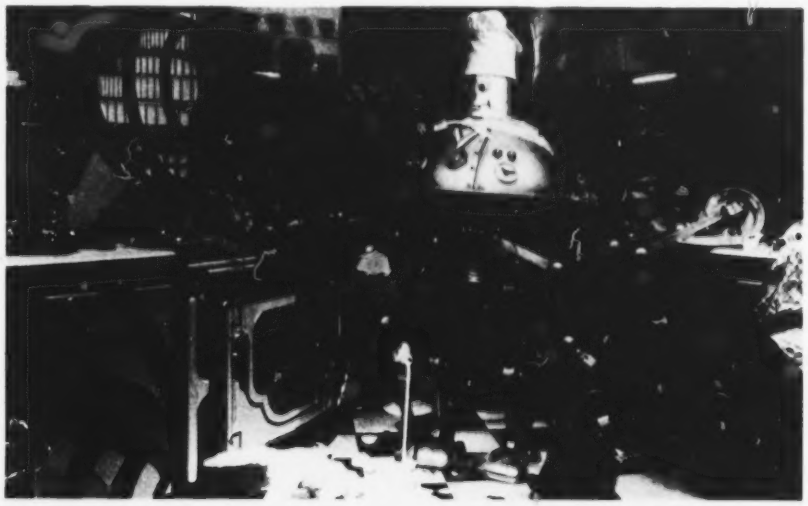


FIGURE 4
A robotic "Rube Goldberg" contraption to make kitchen work easier.

FIGURE 5
The risks involved in a lunar landing were great, but resulted in many new discoveries about the moon's surface.

phone. Some of these inventions like the photophone did not work out. Others like the iron lung worked.

Taking risks requires courage. Courage is repeatedly a strong emotional characteristic of highly creative people. In the final analysis, creative men and women pit themselves against existing ways and systems for solving problems no matter what risk taking it requires.

Using chance is taking advantage of the unexpected. Sometimes people refer to chance occurrences as serendipity. The discovery of the process of vulcanization of rubber occurred to Charles Goodyear by chance. One day he carelessly dropped some raw rubber against a hot potbellied stove. When he saw the way the charred area looked and felt, he recognized that heat was the solution to the problem. He later experimented with a number of other methods, but his chance encounter with the stove proved to be the best solution.

Louis Pasteur said, "Chance favors only the prepared mind." Indeed, daydreaming may produce new creative ideas. However, random daydreaming in a mind that does not contain the required tools for thinking is unlikely to produce new ideas.

Constructing networks is forming associations between people for an exchange of ideas, perceptions, questions, and encouragement. A net is stronger than its individual strands. Letters, meetings, discussions, and reviews stimulate ideas. They also serve to encourage the creative thinker when they become discouraged or disillusioned.

Shared ideas and information is the essence of "technology transfer" which forms the basis of the "NASA Tech Briefs." This publication provides abstracts about new discoveries at various NASA research centers. Thus creative people within NASA are able to share their new discoveries with others.

The process of technology transfer has led to a number of spinoffs from the space program. Notable among these spinoffs is a wheelchair that weighs only 25 pounds, but has the capabilities of a chair weighing twice as much. It resulted from the use of aerospace composite materials as well as technology in computer-aided design that allowed its structure to be easily drawn.

For the creative process to be successful many elements must be brought together. In Figure 6, the Mind Crystal, the interrelationship of ideas that must be networked to produce creative output is illustrated.

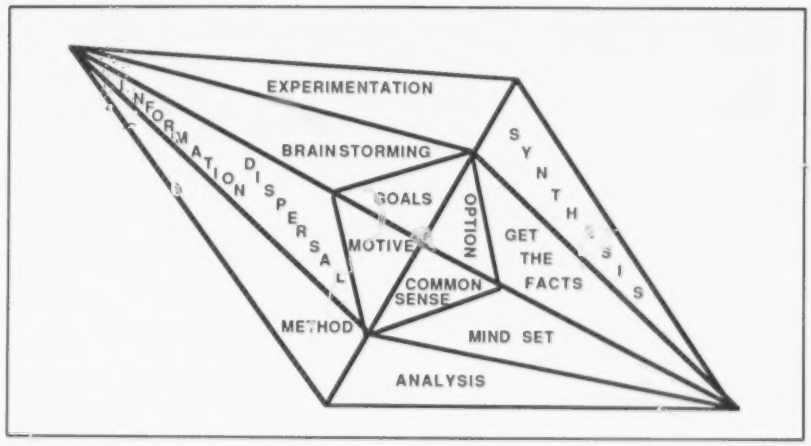


FIGURE 6
The Mind Crystal

Social/Cultural Impacts

Often ideas that result from the process of creativity are worthy enough to be produced in small amounts or manufactured in large quantities. Translating the ideas generated by creativity to the marketplace requires the skills of many professionals. Most of these professionals are employed by industry and the government. Prominent among these people are the designers.

The designer uses the design process to make the abstract, creative process of thinking become concrete. The job of the designer is to pick up from the developer (inventor) and modify the product or device so that it can be produced. Both creativity and economics play a vital role in the process that brings saleable products to the world marketplace.

The design process has been described by many authors as a systematic process consisting of many steps taken by the designer when confronted with a technical problem requiring a solution. It is a repeating process in that it requires the recycling of previous steps, backstepping, as well as jumping ahead at times to more advanced steps in the process. New data calls for revisions to previous conclusions. In summary, the process transforms creative ideas into desired, useful products or processes.

A truly creative person who has learned to visualize solutions to a problem can be frustrated if he/she has not learned how to translate his/her creative ideas (mental images of the form and function of a new idea) into some visually recognizable form. This form is known as drawing.

The oldest method of drawing, freehand drawing or sketching, will be reviewed since it is an essential tool of the designer. Actually, freehand drawing is just one of several major bodies of theory that comprise the "universal language" of creative individuals. Others include descriptive geometry, vector analysis, and empirical equations.

In this article we will concentrate on just one. In the design process, sketching plays a dominant role. Humans, until the beginning of the 19th century, depended on this method of drawing to record their experiences and thus communicate to future generations some essence of the age in which they lived. It is fitting to point out that recently, in attempting to communicate with possible life forms outside our own solar system, we chose appropriate drawings to convey some salient facts about our civilization. This is exemplified by the U.S. space vehicle Voyager 1 which was launched in 1977 and flew past Saturn (1980) and into the vast reaches of space (Figure 7).

Drawing is both a thinking process for recording the mind's images and a technique of communication. The inventor/

creator communicates with other members of his/her design team. At a later time, sketches will be transformed into instrument drawings by a technician member of the team. Hard models by craftpersons may be produced from such drawings as well. When communicating with nontechnical support personnel, sketches and drawing generally convey a higher level of understanding than do written descriptions. Finally, such drawings can be understood by foreign technical personnel with limited knowledge of the English language.

The person that one should have in mind when he/she thinks about their abilities to sketch is Leonardo da Vinci (1452-1519). His remarkable sketches are so realistic that today, over 500 years later, people can readily understand them. All of us cannot measure up to the genius of da Vinci, but we all possess to varying degrees an ability not only to think creatively but also an ability to convey our ideas onto paper. Secondly, sketching with a pencil what our eyes see (what we perceive in our own mind, the imagination) is the first step in learning the language of the inventor.

As we read the advances of technology brought on primarily by research, design, and development, inventors have greatly affected our society. Even the tools used to sketch (pencil and paper) have been affected by technological change. Now CAD (Computer Aided Design/Drafting) allows sketches to be executed on a computer terminal.

Computer graphics involve the application of computers to the solution of spatial problems and communicating these solutions in a visual form. The CAD, CAE (Computer-Assisted Engineering), and CAM (Computer-Assisted Manufacturing) readily attest to the introduction of computer graphics in the design process.

Drawings are produced and sent electronically to computer controlled machine tools along with a set of detailed instructions for manufacturing the object. The new knowledge acquired in materials science/engineering have allowed engineers to downsize digital computers to such an extent that a personal computer has become an essential tool of all inventors.

The creative person must be able to type and compose documents on a computer keyboard and after editing and proofreading store it in a computer, send it electronically to some other computer station, or print its output. To do this the person must be familiar with the computer's commands, have a good working knowledge of word processing, spread sheet, and various data base programs. All of this activity can be accomplished without human intervention during any phase of the process.

This new innovation in computer applications will allow the designer to place greater emphasis on the creative aspects of the design. But just as the student driver of an automobile or the student pilot of an aircraft needs to learn the basics of a new endeavor, so too, the designer who sets out to learn how to design on a computer must learn the basics through the traditional use of pencil and paper (Figure 8).

In summary the person who wishes to be creative must be willing to challenge assumptions, recognize patterns, see things in new ways, make connections, be willing to take risks, take advantage of chance, and be able to construct networks. Creativity can be a learned skill. This skill can be applied to the technological world to improve the quality of our life.

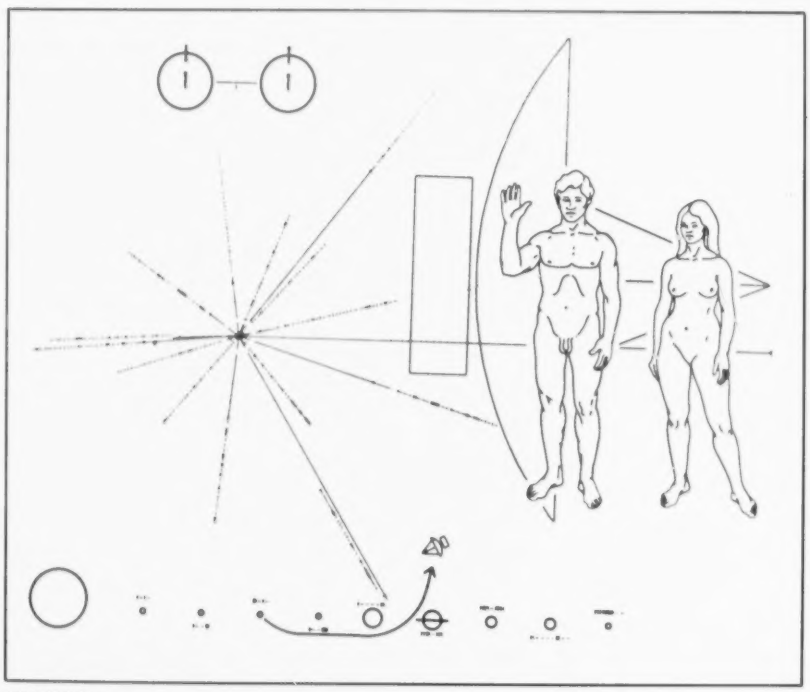


FIGURE 7
The drawing on Voyager 1.

FIGURE 8
CAD is used to design a new communications network.

Math/Science/Technology Interface

The following is a brief biographic listing of a number of scientists/technologists. Read these and see the contributions they have made to further the quality of our life.

John Wilkinson was an early technologist whose developments with machine tools laid the foundations for the industrialization of the world. He developed a boring mill which was used to bore cylinders and condensers for steam engines. Combining his creativity with that of other early technologists, i.e., Henry Maudslay, James Nasmyth, and Joseph Whitworth, the machine tool industry was started. With complex, accurate machine tools, other tools could be developed to make thread, utensils, or new means of transportation and communication.

Marie Curie was a technologist who added much knowledge to the field of radiology. Her first major contributions were the discovery of polonium and radium from pitchblende. Later with her husband, Henri, Marie isolated radium in its pure form. For their work in chemistry and physics they were awarded two Nobel prizes.

Robert H. Goddard was the father of modern rocketry. During the 1920's he worked with rocket design and their propellants. He also worked on the first liquid fuel rocket, the bazooka, a jet propelled research plane, and airplane stabilization. During his lifetime, Robert Goddard was credited with over 150 patents.

Thomas A. Edison was very curious as a child. This creativity lead to the development of one of our most famous technologists. Over his lifetime, Edison is credited with over 1000 inventions including such developments as the telegraph, electric light, stock ticker, and transmitter/receiver.

Who are other scientists/inventors/technologists who have been labeled as creative individuals? Can you add to our list?

Goodyear	Marconi
Jobs	Westinghouse
Ford	Engleberger
Daimler	Deere
Carver	Remington
Fulton	Oppenheimer
McCormick	Wright
Watt	Sikorsky
Volta	Howe

(Have your students conduct research to find out information about these and others.)

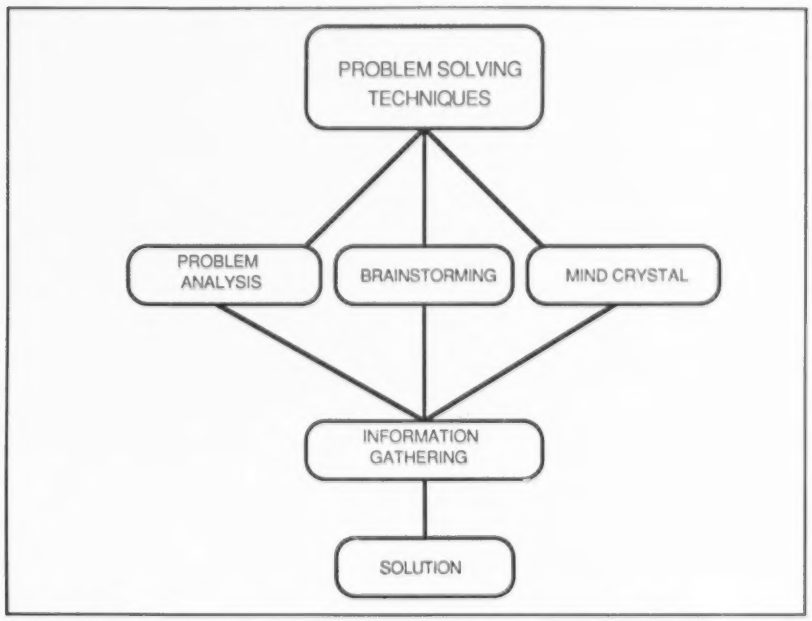


FIGURE 9
Flowchart to help solve problems creatively.

Constructual Activities

How do we actually solve a problem? Here is an approach that has proven effective. The following flow chart illustrates the path that you might take in solving a complex problem creatively (Figure 9).

Let us assume that you have four bricks. The problem is to arrange them in certain specified ways. These specifications tell you how the bricks come to touch one another in a specific arrangement. To count as touching, two bricks must have a flat surface touching, not a corner or an edge.

The Arrangements

Problem One—Place the bricks so that each brick is touching two other bricks.

Problem Two—Place the bricks so that one brick is touching one other, one brick is touching two others, and another brick is touching three others.

Problem Three—Place the bricks so that each brick is touching three others.

Problem Four—Place the bricks so that each brick is touching one other.

Possible Solutions

Answer One—There are several methods to do this. One way is shown in #1 in Figure 10. This "circular" brick arrangement has each block touching two neighbors, one in the front, the other in the back.

Answer Two—This second example is difficult because most people assume that it must be solved in the order that it was given (e.g. one brick touching another, one brick to touch two others . . . etc.). By using creative analysis, viewing the problem from a different perspective, we may start at the other end of the problem and work backwards. First we make one brick touch three others then this grouping can be modified to give the arrangement shown in #2 in Figure 10.

Answer Three—In this example again an assumption is made. Most people think that the bricks must all be in the same plane. If we assume a 3-dimensional arrangement we can place the bricks on top of one another and solve the problem. Here the process of brainstorming with a group of others can be helpful. The generation of a number of solutions by more than one person often

brings out new patterns for solving a problem (#3 in Figure 10).

Answer Four—Many people say that this arrangement of the bricks is impossible. They usually want to arrange the bricks in a long row as shown in #4 in Figure 10. In such a row the end blocks are touching but the middle bricks are touching two others (#5 in Figure 10).

Other Problems

Now try to apply the same principles used to solve the problem involving bricks to the following problems.

The dancing squares puzzle is another activity that is used to see how creative a person can be (Figure 11). In this activity the squares are cut to create the diagrams of six dancers? Can you solve the square and triangle problems? (Figure 12 and 13)

Here are some other design activities you may wish to undertake.

- Design a system to replace door knobs and latches. Use a school setting with typical students carrying an armful of books while trying to open a classroom door.
- Design a residential electrical system that eliminates receptacles, switches, as well as cords.
- Design a safer skateboard.
- Choose a problem that is in your school or laboratory that could be solved by the creative approach and solve it.

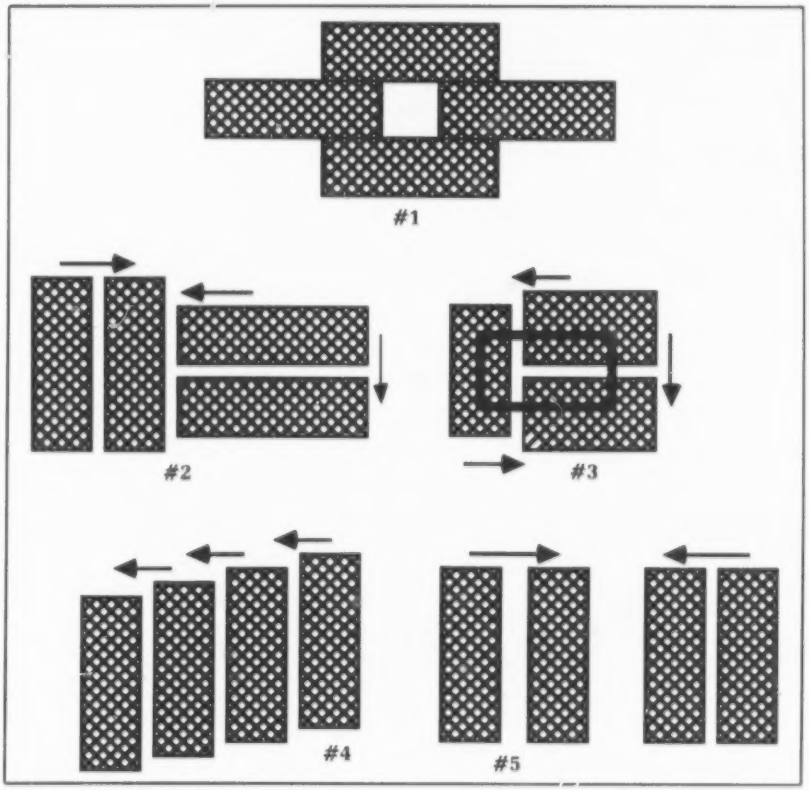


FIGURE 10
Answers to the brick problems

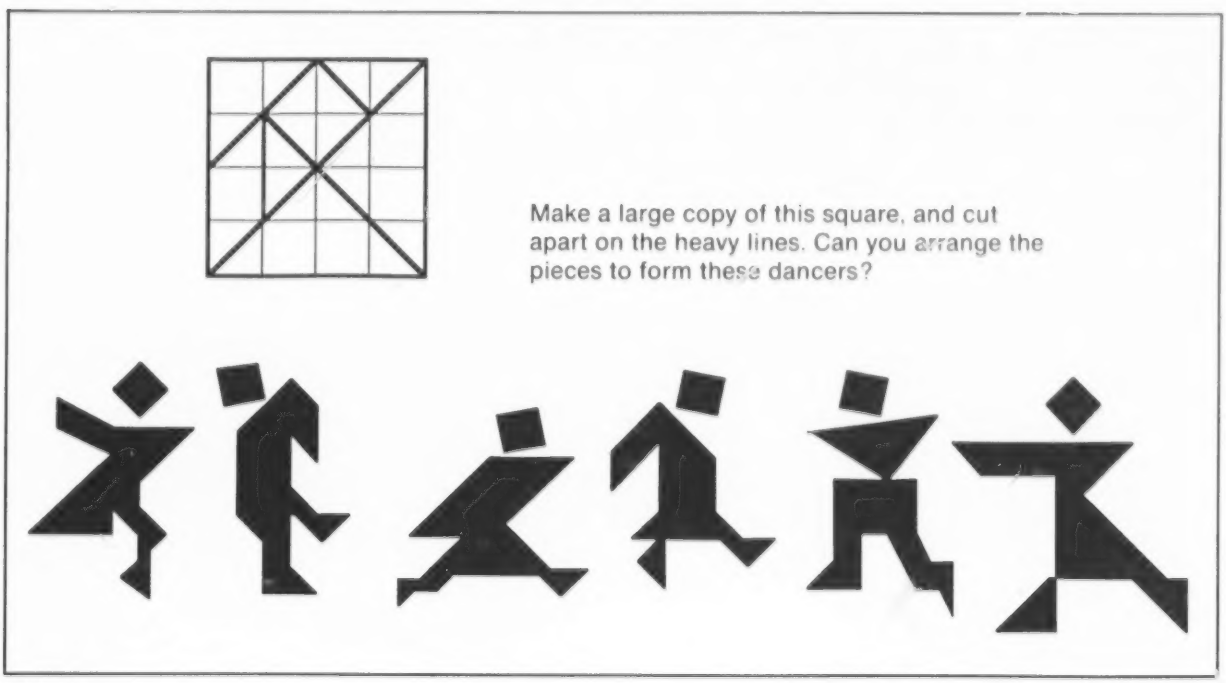


FIGURE 11
The Dancer Problem

How many ways can you divide this square into four parts of exactly the same size by drawing lines from dot to dot? This exercise may challenge your assumptions about squares.

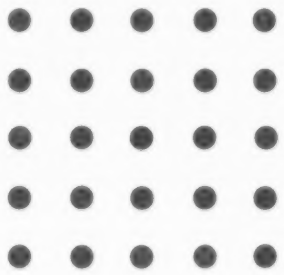


FIGURE 12
The Dot Problem

How creative are you?
How many triangles can you find in this figure?

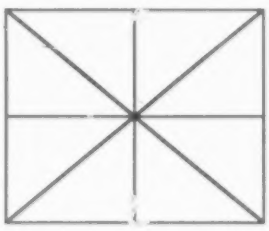


FIGURE 13
The Triangle Problem

Summary

Creativity is a tool that is useful in technological as well as developing societies. Our ancestors used creative means to fashion the world as we know it today. Creativity can be learned if we have certain innate abilities such as ambition, perseverence, enthusiasm, and high energy levels. The creative individual must also study to gain knowledge about particular subjects and be a thinker—one who explores new avenues. If an individual possesses these traits, he/she can be trained to become more creative. They must learn about the creative process and be challenged with various types of problems.

This is where the technology education program can shine above others. Using our laboratories, with their machines and materials, teachers can challenge students to use their creative abilities to solve both abstract and concrete problems.

Quiz

1. What are the innate abilities usually possessed by a creative thinker?
Ambitiousness, perseverance, enthusiasm, energy, knowledge, and thinking ability
2. Outline the steps used to carry out the creative process. *Challenge assumptions, recognizing patterns, see in new ways, making connections, taking risks, taking advantage of chance, constructing networks*
3. What is meant by networking?
Forming associations between people for an exchange of ideas, raising questions, and encouraging further research.
4. What does a designer do in his/her work?
Pick up from the developer and modify the idea, product, or device so that it can be produced.
5. What are the tools used by designers?
Pencil and paper, computer, CAD, CAE, CAM, prototypes, etc.

Possible Student Outcomes

1. List the elements of the creative process.
2. Describe how creativity is used in industrial settings.
3. Cite technologists and their contributions to the development of our technological society.
4. Apply the creative process.

References

Beakly, G. Evans, D., & Keats, j.B. (1986). *Engineering: an introduction to a creative profession*. (5th Ed). New York: Macmillan.

Buzan, T. (1974). *Use both sides of your brain*.,New York: Dutton.

deBono, E. (1982). *deBono's thinking course*, New York: Facts On File.

deBono, E. (1970). *Lateral thinking: creativity step by step*. New York: Harper & Row.

deBono, E. (1985). *Dr. Edward deBono's masterthinker's handbook*. New York:International Center for Creative Thinking.

Eide, A. R. et al (1985). *Engineering graphics fundamentals*. New York: McGraw Hill.

French, T.E., Vierck, C.J., & Foster, R.J. (1986). *Engineering, drawing and graphic technology*, (13th Ed). New York: McGraw Hill.

Pranes, S.J. & Harding, H.F. (1962). *A source book for creative thinking*. New York: Charles Scibner.

Reel, E. & Morring, B. (1983). *Engineering: fundamentals of problem solving*. Los Angles: Wadsworth.

Museum of Science and Industry. (1985). *Technology: chance or choice?* Chicago: Author.

Yepsen, R.B. (1987). *How to boost your brain power*. Emmaus, PA: Rodale Press.

Resources in Technology

Introduction to Artificial Intelligence

Contemporary Analysis

There is no question that computers are important technological tools in an information-based society. In business, industry, and, yes, even in the home, computers are used to manage information, design and produce products, and assist us in learning. Of course, entertainment is another application of computers that should not be overlooked.

For the last 40 years, computers have been a real asset to those who know how to use them as information management tools. There are many of us that know what we want a computer to do, but do not know how to communicate our wishes to the computer.

Researchers and computer scientists have been working to solve the problem of making computers more intelligent. This research is called artificial intelligence. Artificial Intelligence (AI) and the related study in Expert Systems (ES) are a part of computer science and cognitive psychology that attempts to bridge the gap between the human and the machine.

This issue of Resources in Technology *will introduce the concept of Artificial Intelligence, discuss where AI is currently being used, and provide an illustration of an expert computer system that can be used in the technology laboratory. The accompanying activity describes ideas for using "intelligent" computers as problem-solving tools.*

The goal of AI researchers is not to design computers that are more intelligent than human beings, but rather to design systems that think *like* humans and can solve problems of a variety that machines are good at.

For example, multiplying two numbers together, 1,234 × 5,678, is a mathematical skill that we can accomplish with pencil and paper. Some people can perform that multiplication task in their heads with little difficulty. However, a calculator or computer can perform the same task much more quickly and accurately. Which method would you choose? Pencil and paper? Or a computer?

Computers are capable of processing numbers rapidly and accurately. We call this information processing. Computers are capable of processing numbers and information so rapidly that there are tasks they can do that it would take you or I several lifetimes to do.

An important feature of computers is their capability to store information—very large quantities of information. Imagine what it would be like to store (remember) just one page of telephone numbers from your local telephone directory. But not only can computers store information, they can almost recall stored information instantaneously with just a few keystrokes!

People have traditionally been better at doing some things than computers could do. Intelligence and understanding are characteristics we humans have that computers don't. AI researchers are working to develop more intelligent computers. That is, they are trying to make computers perform in a manner similar to the way that humans think and work.

Arvon Barr and Edward Feigenbaum have defined AI as "the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behavior" (Barr & Feigenbaum, 1981-82, 1:3).

There are several important areas in AI where research is taking place. These areas include:

- Expert systems
- Natural language processing
- Speech recognition
- Computer vision
- Robotics
- Intelligent computer-assisted instruction (ICAI)
- Automatic programming
- Computer decision support capabilities

Business and industry are seeking ways to improve efficiency and accuracy in their operations. Training and educational developers are looking for ways to provide intelligent computer-assisted instruction.

In each of these categories the focus is to develop software that imitates the

human characteristic of understanding. For example, if a person has problems using a computer system and repeatedly makes the same errors, then it is obvious that the person is having difficulty in using the system. But the system does not "understand" that the person is having a problem. The computer just responds with a familiar "Beep!" or displays a message that the user has a "syntax error." Certainly most computer users have experienced these problems at some time.

However, suppose you were using an intelligent computer to retrieve a file name you thought was named "NEWTECH," but were having difficulty in loading the file. After you made several errors the computer would suggest " . . . you have misspelled the file name. The correct spelling is NUTECH. Please press the <ENTER> key twice to load the file called NUTECH."

This illustration shows how smart computers can access a knowledge base to offer "expert advice" to a computer user. Basically, the operations that a computer user is performing are compared to the operations of what an expert person would do under the same conditions. When the inexperienced user continues to make a series of errors, then the "expert" offers advice.

Expert Systems

As described earlier, Expert Systems (ES) is a branch or part of the area that we call artificial intelligence. Recently ES has made great inroads in developing and marketing computer software. There are many people in need of expert advice or consultation on topics ranging from medicine to oil exploration.

You might ask "How can an expert system help in these and other situations?" Well, they can. An expert system is like having an expert's knowledge stored in a computer data base. Or like having many of your teacher's experiences stored in a computer system that can be accessed just by entering ordinary questions.

For example, you could ask your computer what would be the best adhesive or cement to use on a project you're making. This is the essence of an expert system.

An expert system can be defined as a computer system that has a knowledge base of facts and information, procedural rules for accessing and making conclusions from the knowledge base, and user interface. The important feature of an expert system is its capability to analyze facts included in its knowledge base and present a conclusion or recommendation based on those facts.

Thus, the information contained in a knowledge base is declarative (facts) and procedural, that is presented according to logical rules similar to human reasoning.

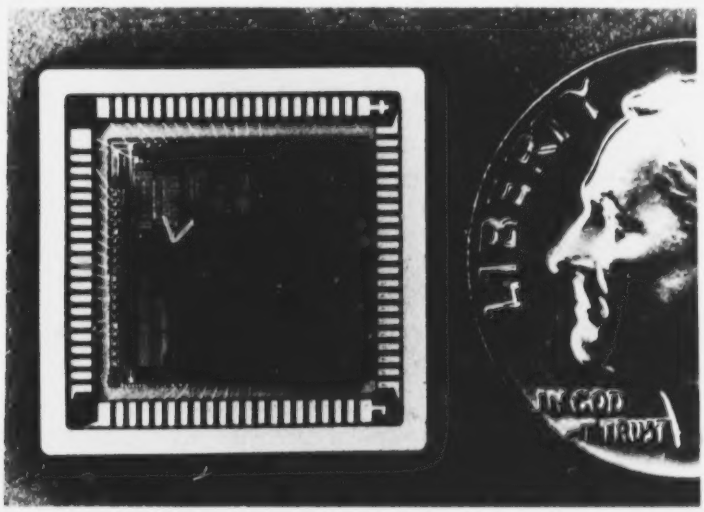


FIGURE 1
This silicon chip contains 150,000 transistors, much less than the 500,000 or 1,000,000 of some newer chips. One can see the problem in trying to route the micro conductors paths that are as small as 50,000,000,000ths of one inch.

Social/Cultural Impacts

Today in business and industry, Artificial Intelligence and Expert Systems effect how things get done and how complex problems are solved. For example, transportation ES have gone to sea.

BALLAST is a system that helps marine personnel distribute cargo they load in ships to insure the best attitude of the ship, better fuel efficiency, and crew safety. This "trimming" of the ship is done in just minutes, a task that formerly took hours. The systems can also help if an accident causes cargo shifts and intake of water (*High Technology*, July,1987).

Another example of an ES in use for production is the EXCABL program developed for routing electrical cable in the payload bay of the Space Shuttle Orbiter. Because of the difficulty of remembering how all the cables are placed and to insure neat folding of the electrical cables into available space, an ES program automatically determines the routing process and generates data for cable installation based on knowledge fed into the program by cabling experts.

EXCABL closely matches the XCON ES program developed for configuring VAX computers that also required tight fitting of components, ease of maintenance and regular changes in configuration (*NASA Tech Briefs*, p.48).

Intelligent CAD Workstations

An example of ES for design was mentioned earlier with EXCABL that was used for cable routing on the Space Shuttle Orbiter. Design of very large scale integrated (VLSI) computer circuitry has become a task beyond human capability. A single silicon chip about the size of a dime has as many as 500,000 transistors, so it has become impossible to keep track of the conductor paths and the individual transistors (Figure 1). Additionally, the demand for specialty computer circuits means more VLSI circuits must be designed than ever before.

An ES such as XCON (for "expert configurer"), discussed earlier, provides the electronic circuit designer with automatic design tools as a part of a CAD program. This program aids in the placing transistors, diodes, and routing the conducting leads, thus reducing the number of designers and time needed to complete a design.

Development of an ES to aid in design aims at using personal computers and insuring that AI promotes dialogue between system and human rather than just asking the designer to provide yes/no answers. (That is to make sure the computer solves problems similar to the way humans do so that the solutions appear reasonable to the designer).

Knowledge engineering is required of ES to develop the proper problem-solving techniques plus gathering and keeping updated the knowledge base for the system. Some knowledge bases are readily available in books such as the stress analysis data. However, failure analysis requires an expert's experience because of the variables of environment, varying stress, and quality of material. Mechancial-engineering ES by Tektronics tries to look over the shoulder of the designer to closely mimic human thought (Aldersey-Williams, p. 38 & 39, 1987).

Modeling and Simulation

ES for design of manufacturing lines aids manufacturing engineers and reduces the possibility of layout and scheduling errors by providing graphic aids showing how the production line will operate (Figure 2). The intelligent systems are capable of learning by automatically accumulating, filtering, interpreting, and storing data to improve the control structure of the production line (McLean 1985, p. 6).

IntelliCorp markets the production line knowledge-based simulator SIMKIT that provides manufacturing engineers with an interactive ES system that aids their design and may preclude the building of scale models (Figure 2) of a line (Powers, pp. 102-104).

Process Planning

The Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards (NBS) in Gaithersburg, Md., has served as a test bed for developing software and hardware for automated manufacturing of metal parts. A LISP-based program provides intelligent process planning functions such as making a plan from a design, selecting machining operations to make designed features and selecting tools for machining operations as seen in Figure 3. Note the experience data base that serves as input to aid the designer.

ABSTRIPS is a ES planning system that devises plans for a robot to move objects between rooms. NOAH is an ES for robot planning that assigns operating

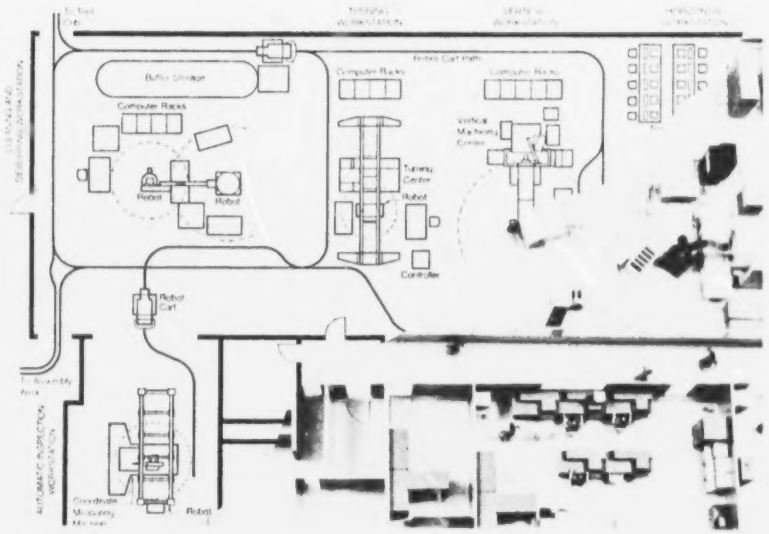


FIGURE 2
Scale models are costly to develop but provide essential information on production line advantages and disadvantages prior to building the line thereby saving time and money. With a CAD workstation, the layout of the Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards can be stimulated (top) and the feasibility of different ideas easily checked. This compares with the traditional scale model (bottom).

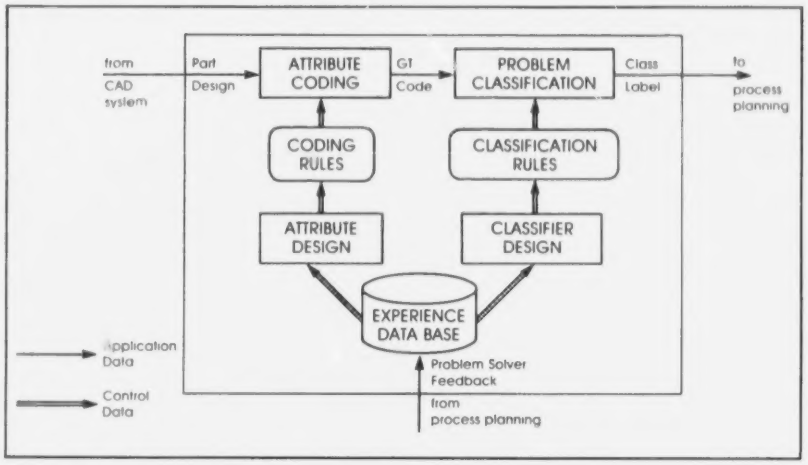


FIGURE 3
Group Technology keeps together similar part and materials processes and experience data bases get the most of experts knowledge on how to grouping for most efficient processing. Here we see the flow of information in process planning.

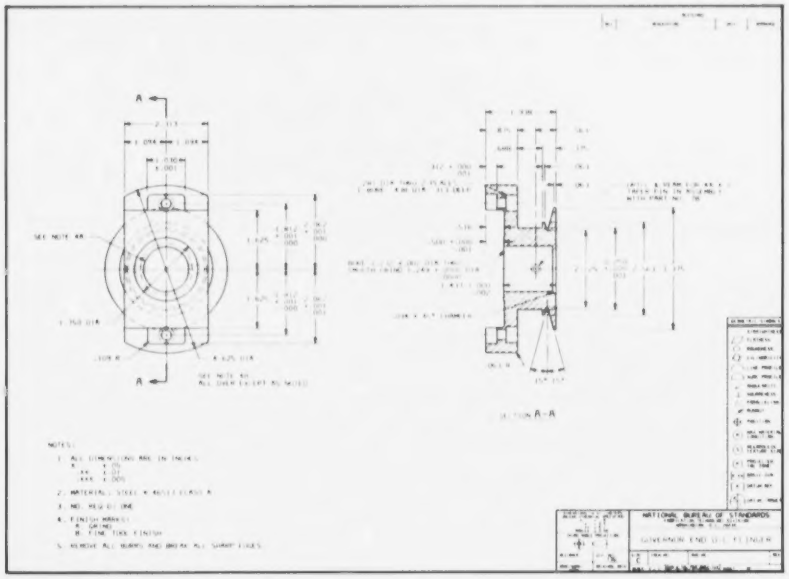


FIGURE 4
Using AI in process control. The first step is a CAD generated drawing show a part for processing.

Process Planning Data Structures — The Workstation Operation Sheet

Operation Sheet # _____ Version # _____ Date _____
Workstation Type _____

Input Part Geometry _____
WIP Part Geometry _____ Total Processing Time _____
Output Part Geometry _____

← Operation Sheet Header Contains Identification and Summary Data

Step NR	Initial Geometry	Final Geometry	Equipment 1 — Robot	Equipment 2 — NC Machine	Equipment 3 — Fixture	Time
1						
2						
3						
4						
5						

← Detailed Listing of Operation Steps

Variable Number of Operation Steps

← Equipment Columns as Required by The Current Workstation Configuration

FIGURE 5
The next step is a Workstation Operation Sheet that aids in determining how to develop CAM data for CNC machining and other processing steps.

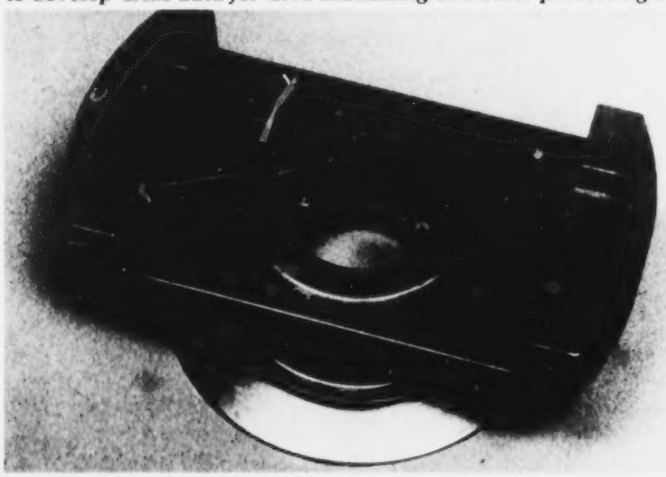


FIGURE 6
The finished product machined to meet the CAD specifications.

sequences of robot arm movement and prevents interferences (*An Overview of Expert Systems*, May, 1982 p. 61 & 62).

Process Control

Once the production line is designed with the various material processes planned, it is necessary to control and monitor each process to insure product quality. This process is represented by the three items shown in Figures 4–6

- CAD generated drawing
- A workstation operation sheet used to develop process plans
- Finished machined part

Robots and automated machine tools CNC (computer numerical control) can be programmed to change their own tooling at the appropriate time.

Adaptive control provides intelligence to these computer-controlled tools so as tools begin to wear and become dull the CNC tool adjusts the coolant, speed and feed of the tools to maintain specifications and prevent catastrophic failure of the tool which would ruin the workpiece.

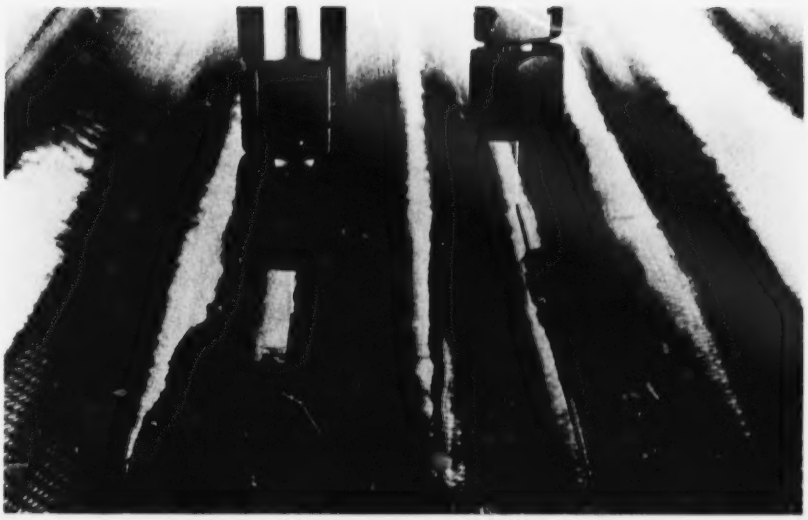
An intelligent process control system can keep track of thousands of processes as one might find in the production of silicon computer microprocessors. Such production systems require monitoring and controlling of very clean environment to insure that no impurities contamine the semiconductors.

Smart Robots

Many people conjure up notions from "Star Wars" when they think about robots or envision robots capable of moving about much like humans with great arm, hand and finger dexterity. The truth is that today's robots are dumb machines with limited flexibility; most have no mobility. The major feature robots possess that make them desirable in manufacturing is their capability to be reprogrammed to perform different tasks without major overhaul as required in hard automated machinery.

Applying sensors to robots to improve their capabilities in manufacturing operations makes a move toward the "smart robot." Sound sensors that one finds on Polaroid cameras are available in kits for manufacturing. Robotic automated guided vehicles (AGV) employ sound sensors to insure they do not collide with objects or people. Other sensors such as machine vision and tactile (feel) sensing will move robotics toward the goal of making machines perform human tasks in a more human fashion.

FIGURE 7
Water jets can cut through most materials such as space-age composites like Kevlar without the thermal effects that come with traditional cutting tools.



Machine vision now used on robotic systems helps to determine proper shape and orientation of parts. To couple problem-solving capabilities (AI and ES) with sensors will provide a truly smart robot that will better serve manufacturing.

Among the other values of AI presented here, the ability to use natural language and recognized speech would further the smart robot's ability to learn the task that an engineer or technician may wish to teach it. Currently, robots learn their commands by programming from computer software or by the use of teach pendants. These systems require time and special knowledge which AI could overcome.

The development of manufacturing technologies such as water jet and laser cutting (Figure 7) with AI promise to make robots even more valuable in manufacturing.

Shifts in the type of jobs predicted for industrial robots in the year 2000 reflect a confidence that robots will be much smarter and more versatile. For example, one study predicts a decline in welding and painting (from 46% to 25%) which requires less precision while robots for assembly will increase from 16% to 35% since AI systems and greater accuracy will make these machines more cost effective. The same study projects that industrial robots will grow from 4200 units in 1984 to 22,000 in 2000 (Porter, June 1987, p. 27).

Product Testing and Development

Data generated from CAD/CAM operations provides for automated testing and inspection of parts during processing. Coordinate measurements generated from the CAD systems provides for designated locations on the part geometry which a probe can locate to see if the part is being machined to specifications. A knowledge base of design and test information help to improve the procedures through an inspection control hierarchy as seen in Figures 8–10 in which inspections are determined and developed at a CAD workstation, then used to direct the robot manipulated probe to inspect parts.

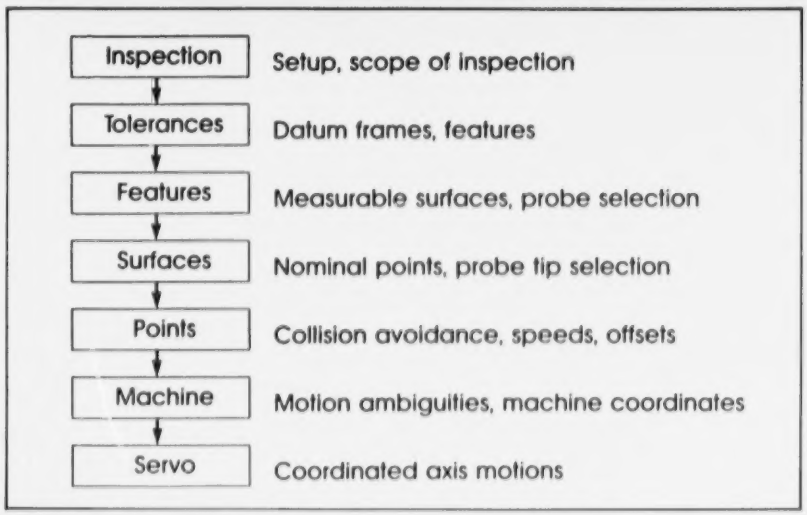


FIGURE 8
This inspection control hierarchy shows how the inspection sequence interacts with the process plan.

Constructional Activity

An activity developing an expert system provides an excellent opportunity for developing problem-solving skills. A research and experimentation approach is suggested for this activity. One or more expert system development teams should be organized to develop an expert system package for the class. Each team should have a team leader, knowledge engineer, and one or more expert researchers/interviewers.

The team leader is responsible for coordinating the team. The researchers or interviewers would research a team-identified area of expertise for inclusion in the knowledge base. The knowledge engineer would develop the procedural rules from the knowledge or expertise identified by the researchers. The development team would be responsible for identifying a student problem area that could benefit from the advantages of an expert system.

Expert system development topics can easily be found in communication, production, and transportation. For example, a topic could be defined as "diagnosing offset composition problems," "film selection for black and white and color photographs," or "diagnosing traffic congestion problems."

A major emphasis is identifying and

collecting facts for the knowledge base and writing "rules of facts" representing that knowledge.

The suggested steps for the development process are as follows:

1. Identify and select a problem area where an expert system can be used as an improvement tool.

2. Through a cooperative effort, define the problem area by listing the problems individually.

3. Provide the opportunity/environment for the team researchers to identify the expertise or resources for developing solutions to the problems. The interviewers should use an interview or research technique to prepare a listing of the factual information similar to Figure 11.

4. Provide the opportunity/environment for the knowledge engineer and researcher to isolate problems and all solutions to the problems so as to develop the procedural rules for the expert system.

5. Prepare the knowledge domain and procedural rules for accessing the knowledge base.

6. Development team would test, evaluate, and revise their expert system. Upon completion of this phase, the expert system product would be ready for use by other class members.

Equipment and Materials

The activity will require an expert system software package such as the VP-EXPERT, Prolog, or TURBO PROLOG AI language. Additionally, a computer system compatible with the expert system development software is required. Recommendations for equipment and software for developing problem-solving activities in artificial intelligence and expert systems are included in the equipment list.

Materials and Equipment List

Hardware

- IBM PC-XT, or compatible computer with two disk drives, at least 384K memory, and monitor

Software—one of the following packages

- EDPROLOG from Automata Design Associates, 1570 Arran Way Dresher, PA 19025
- TURBO PROLOG from Borland International, 4585 Scotts Valley Drive Scotts Valley, CA 95066
- VP-EXPERT, Paperback Software International, 2830 Ninth Street Berkeley, CA 94710

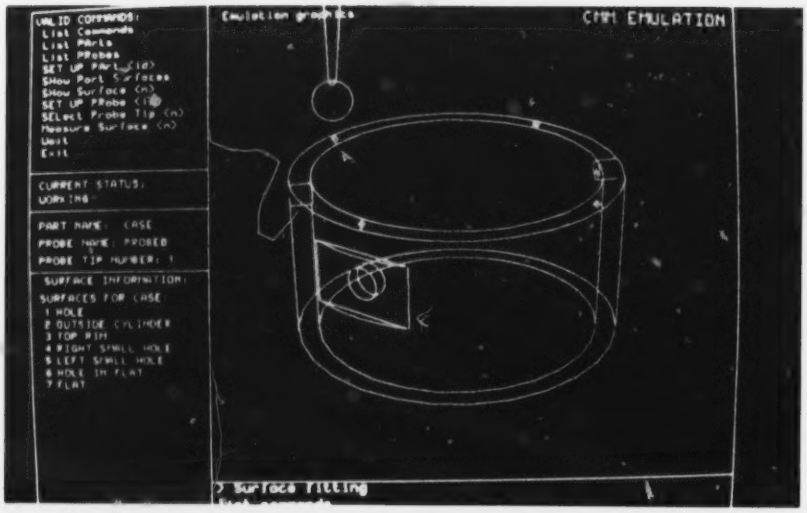


FIGURE 9
The intelligent workstation can be used to generate data to direct the probe for part inspection as seen in this picture of the CAD screen.

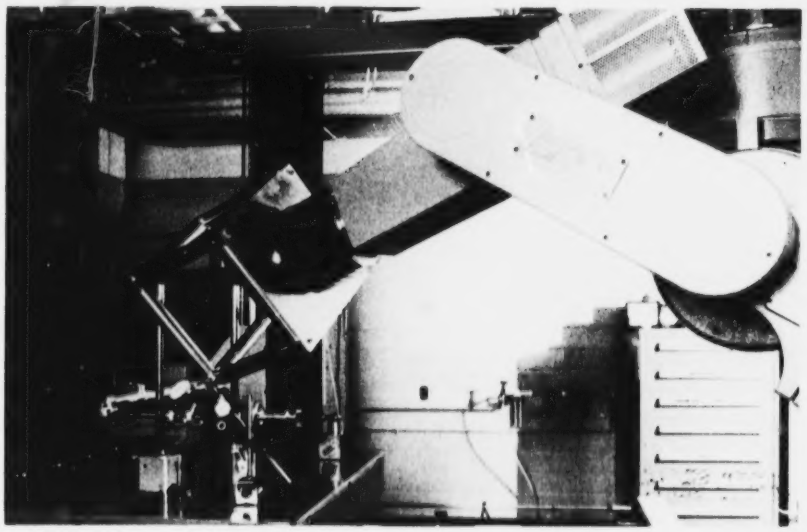


FIGURE 10
A probe attached to a robot end effector provides automatic inspection of machined parts once the robots has been programmed to make specified measurements.

Math/Science Interface

To illustrate a process of developing an expert system we will define a knowledge domain, define a knowledge base, and prepare knowledge rules that represent a knowledge base. For example, in developing a knowledge base for selecting adhesives and cement for wood, plastic, and metal materials, we would identify the types of materials, adhesives or cement, and conditions where the assembly or product would be used. Typically we would interview an "expert" on the processes and procedures, or we may find the information in a technical reference manual. The results would be the same; finding the "expertise" related to a given subject area or knowledge domain.

FIGURE 11
Statements or facts that may be used for the basis of a Knowledge Base as part of the process in developing an Expert System.

1. Polyvinyl (white) glue is best suited for wood to wood joints for interior uses.
2. Resorcinol (two-part) glue is best suited for wood to wood joints for waterproof or marine uses.
3. Contact cement is best suited for wood to plastic laminate joints such as counter tops for interior use.
4. Epoxy cement is best suited for metal to wood joints and waterproof uses that are interior or exterior.
5. Epoxy cement is best suited for metal to metal joints that are interior or exterior use.
6. Plastic cement (methylene chloride) is best suited for thermoplastic to thermoplastic or Plexiglas™ bonds for interior or exterior waterproof uses

Listing For Expert System

```
RUNTIME;
ACTIONS
FIND glue;

RULE 1
IF        material = wood-to-wood AND
          use = interior
THEN      glue = polyvinyl
DISPLAY   "The best adhesive is [glue] for your task.";

RULE 2
IF        material = wood-to-wood AND
          use = exterior OR
          use = marine OR
          use = waterproof
THEN      glue = resorcinol
DISPLAY   "The best adhesive is [glue] for your task.";

RULE 3
IF        material = wood-to-plastic AND
          use = interior OR
          use = exterior
THEN      glue = contact-cement
DISPLAY   "The best adhesive is [glue] for your task.";

RULE 4
          material = wood-to-plastic AND
          use = marine OR
          use = waterproof
THEN      glue = epoxy
DISPLAY   "The best adhesive is [glue] for your task.";

RULE 5
IF        material = wood-to-metal AND
          use = interior OR
          use = exterior OR
          use = marine OR
          use = waterproof
THEN      glue = epoxy
DISPLAY   "The best adhesive is [glue] for your task.";

RULE 6
IF        materials = metal-metal AND
          use = interior OR
          use = exterior OR
          use = marine OR
          use = waterproof
  THEN    glue = epoxy
DISPLAY   "The best adhesive is [glue] for your task.";

RULE 7
IF        material = thermoplastic AND
          use = interior OR
          use = exterior OR
          use = marine OR
          use = waterproof
THEN      glue = methylene-chloride
DISPLAY   "The best adhesive is [glue] for your task.";

ASK       material: "What are the materials to be joined and the intended use?";
CHOICES   material: wood-to-wood, wood-to-plastic, wood-to-metal, thermoplastic;
CHOICES   use: interior, exterior, marine, waterproof;
AUTOQUERY;
END;
```

The knowledge or expertise that we had summarized would typically appear as shown in Figure 11. Notice that the summary of the knowledge is stated in terms of "facts." These facts will then be used to develop the knowledge rules for the expert system that we are building.

If each of the statements in our knowledge base is examined, we will find that they contain information about the materials, cement or adhesive, and conditions of use. The knowledge engineer takes this information and prepares expert system rules based on the facts contained in the knowledge domain.

Note, a knowledge engineer is a specially trained person that works with experts and computer programmers in developing Expert Systems.

For example, the following rules are developed from the facts stated in Figure 11, above. The rules are prepared by presenting information or facts in terms of "If-Then" statements.

The above knowledge base is prepared for use with the VP-EXPERT software from Paperback International Software. The knowledge base represents only a part of the total expert system. Figure 12 shows the relationship of the major components of a completed expert system. It should be noted that the illustration included in this article contains *both* the declarative knowledge and procedural rules. In larger, more complex applications the knowledge base would be separate from the procedural rules, thus making the task of expanding the knowledge base relatively easy.

To those persons familiar with writing programs in BASIC, Pascal, or other language, the listing above differs substantially from traditional program structures. The structure of the program is based on rules and facts that are more nearly like how we, as humans, think and solve problems. For example, Rule 1 states that *if* we are going to glue two pieces of wood together that will be used inside, *then* we should use a polyvinyl glue for best results. During the operation or execution of the program. The user would select the type of materials to be glued together and the intended use, interior or exterior, and the inference engine of the expert system would "search" the knowledge base for an

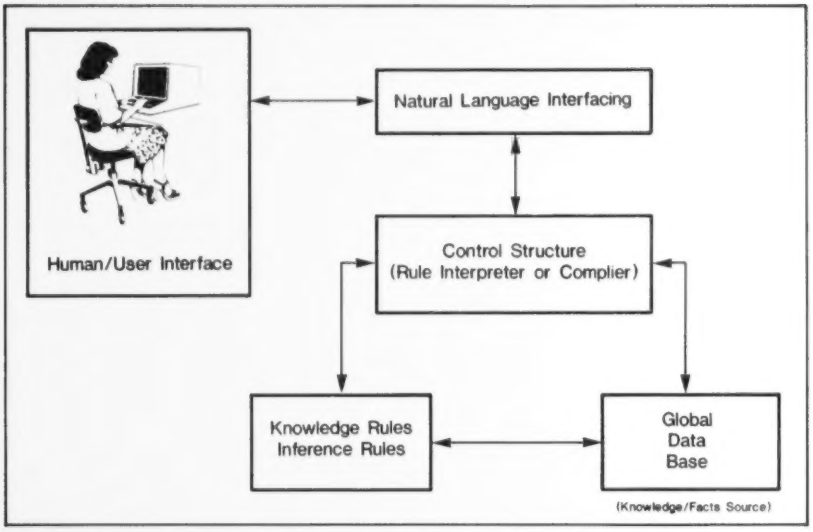


FIGURE 12
The major operational components of an expert system and how they are interrelated. Typically, large expert systems have separate knowledge data bases that are accessed by knowledge rules. The Control Structure interprets the knowledge rules in a logical manner during a session with the system.

appropriately matching rule. The inference engine is a part of the expert systems computer program that is designed to examine and execute, and determine when a solution is found in the knowledge base. Thus, it is a major part of the Expert System.

Summary

As we have seen, artificial intelligence can be defined as a process of designing or making machines that can reason or understand like human beings. Important areas of artificial intelligence include expert systems, natural language processing, speech recognition, computer vision, robotics, intelligent computer-assisted instruction, automatic programming, and decision support capabilities.

Artificial intelligence is finding its way into the fields of education and training. Soon, schools may have access to intelligent computer-assisted instruction (ICAI) systems to supplement the role of teachers. Thus, many applications of AI are part of our future in business, industry, and education. It is melding computer science and cognitive psychology that can provide for the development of machines that are patterned after human intellectual characteristics.

Student Quiz

1. Define Artificial Intelligence.
2. What are the major components of an Expert System?
3. What is a major advantage of the intelligent workstation over an experts knowledge base?
4. List five applications of AI and ES in manufacturing? *intelligence workstations, software development, simulation and modeling, process planning, process control, smart robots, automated product testing and inspection*
5. How does adaptive control aid process control?
By monitoring the coolant, feed, and speed of tools it can prevent tool and part damage while maintaining quality

Possible Student Outcomes

- Define Artificial Intelligence.
- Describe the characteristics of an Expert System.
- List applications of AI and ES in manufacturing.
- Explain the improvements necessary for a change of dumb robots to smart robots.
- Describe the value of intelligent CAD workstations.
- Recall the benefits of adaptive control to manufacturing.

References

Aldersey-Williams, H. (1987, July). "Design with People in Mind", *High Technology*, pp. 34-39.

Barr, A., and Feigenbaum, E.A. (1981). *The Handbook of Artificial Intelligence*, Volumes 1,2, and 3, Stanford, CA:Heuristech Press.

Byers, T.J. (1986, December). *Automation. PC World.*

Davis, D.B. (1986, July). Artificial intelligence enters the mainstream. *High Technology*, pp. 16-23.

Expert system goes to sea. (1987, July). *High Technology*, p. 6.

McClean, C.R. (1985, August). *Architecture for Intelligent Manufacturing Control.* Paper presented to American Society for Mechanical Engineers Conference, Boston.

Meyer, R. J. (1987, April 12). *Applications of Artificial Intelligence.* Paper presented to Robotics 11 Conference, Society of Manufacturing Engineers.

Mishkoff, H. C. (1985) *Understanding Artificial Intelligence.* Texas Instruments.

Program for space shuttle payload cabling. (1987, April). *NASA Tech Briefs.*

An overview of Expert Systems. (1982, May). National Bureau of Standards, NBSIR 82-2505.

Porter A.L. & Rossini, F.A. (1987, June) Robotics in the year 2000. *Robotics Today*, pp. 27-28.

Powers, J.H. (1987). *Computer Automated Manufacturing.* New York: McGraw-Hill.

Staugaard, A.C. (1987). *Robotics and AI: An Introduction to Applied Machine Intelligence.* New York: Prentice-Hall.

Zygmont, J. (1987, February). Manufacturers move toward computer integration. *High Technology*, pp. 28-33.

Acknowledgements

The authors wish to thank the following agencies for the illustrations used in this article.
Figure 1—AT & T Bell Laboratories
Figure 2 to 6, 8 to 11—National Bureau of Standards
Figure 7—Flow Systems

Resources in Technology

Biotechnology

In today's high tech world we read and hear about developments with lasers, robotics, CAD, plasma generation, super conductivity, and many others. We also hear the terms biotechnology and genetic engineering in the press and on television news. What is biotechnology? What will it do for us? Does it have a place in our technological studies? This issue of Resources in Technology *will address these questions and provide an overview of this technological topic.*

Biotechnology combines scientific and engineering methods with technological means. It employs living cells to produce products. Scientists and genetic engineers are manipulating the basic genetic structures of plants, animals, and microscopic organisms to alter them and/or create new products that will be beneficial to us and industry. Many times the terms "biotechnology" and "genetics engineering" are used synonymously.

FIGURE 1
Today scientists and technologists can manipulate the genetic structure of trees to produce superior seedlings and rapid growth.

Contemporary Analysis

Biotechnology is currently used in the areas of bioprocessing technology, recombinant DNA technology, and monoclonal antibody production. Bioprocessing technology uses microorganisms (living cells) to process materials. This is comparable to the use of chemicals to remove rust from metals.

In the past bioprocessing was primarily used to ferment or decompose materials. Fermentation has been used for over a thousand years to make products such as beer and wine. In these cases the bioprocess combines yeast cells with cereal grains. This creates a fermentation system where the living cells in the yeast consume the nutrients in the grain and produce alcohol and carbon dioxide gas.

Bioprocessing is also used to decompose materials. In nature decomposition breaks down vegetation and improves the soil. Many home gardeners have compost piles where they decompose scraps and garden waste which they then add to their gardens to enrich the soil.

Decomposition is also used in the bread making process. Yeast digests sugar

which produces carbon dioxide which causes the bread to rise. Biotechnology has also been used in recent years in the sanitation field. Portable toilets used in camping, construction, and other recreational areas use chemicals that decompose body wastes.

Recombination DNA technology (rDNA) sounds like a mystical area of science fiction. It combines pieces of DNA (molecules that carry genetic information for living organisms) to form improved living products. Although it is a growing area in modern industry and medicine, it has been used since the past century in agriculture. Gregor Mendel first conducted genetic studies of heredity characteristics of plants and animals. These practices continue in animal breeding today. Superior qualities can be passed on into future generations of animals. This is done in the breeding of race horses, show dogs and cats, and prized cattle.

Genetic engineering is also used in the development of plants. Through gene slicing, seeds of plants can be altered to produce qualities that did not previously exist. Plants can be grown that are resistant to disease, need little moisture, produce better looking and tastier fruits, repel pests, or even produce totally different fruits. (Figures 1 & 2)

Scientists and genetic engineers have been creating hybrid plants for years. Research laboratories have come out with new strains of rice and corn that will produce improved yields in tropic and desert areas. Trees have been spliced together to make nectarines (cross between a peach and plum) and dwarf varieties of other fruit trees.

Today scientists, doctors, genetic engineers, and other researchers are experimenting with genetic engineering techniques to cure human diseases such as dwarfism, cancer, heart disease, and bleeding (hemophilia). Genetic engineering is also heavily involved with research in human fertility. Some men and women cannot produce offspring through normal reproductive methods. Using technological means the woman's eggs are fertilized outside her body and then transplanted into her womb for regular growth and birth.

The third area where biotechnology is being applied is in monoclonal antibody production. Antibodies are living cells that defend our bodies against diseases. If we possess certain antibodies we are not susceptible to certain diseases. If our body does not produce sufficient quantities of certain antibodies by itself, their production can be stimulated through injections. Many of us have had shots for the flu, polio, typhoid, cholera, etc. These injections may at times give us a slight case of the infection and/or disease therefore enabling our bodies to produce sufficient amounts of the antibody to fight off the disease/infection.

Most children inherit sufficient antibodies from their mothers at birth. However some do not and are very susceptible to infection and other diseases. Other persons contact AIDS and cannot build up antibodies and consequently may catch many diseases and infections. Biotechnological research seeks synthetic ways to produce antibodies. If living cells can be artificially produced and can be bred within the human body to produce additional healthy, disease fighting cells, then many human, animal, and plant diseases may be curable. Cancer, the common cold, and AIDS may be diseases of the Twentieth Century as the black plague was the disease of the Fourteenth Century.

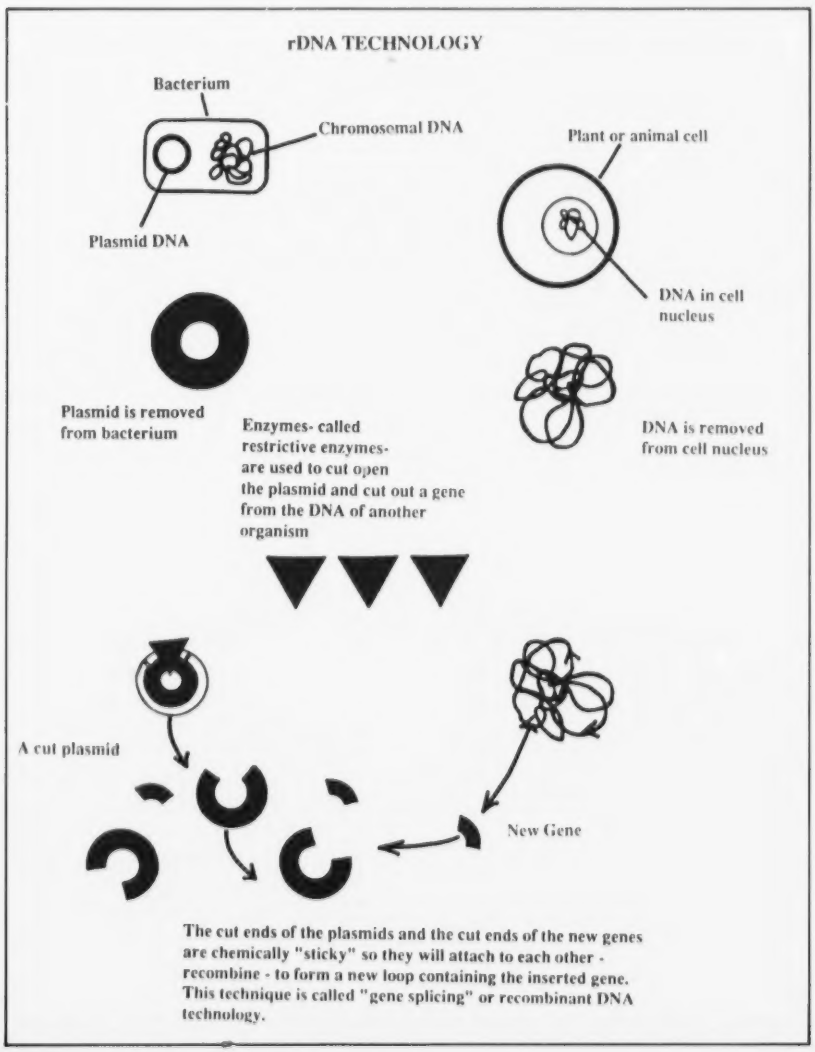

rDNA TECHNOLOGY
Bacterium
Chromosomal DNA
Plasmid DNA
Plant or animal cell
DNA in cell nucleus
DNA is removed from cell nucleus
Plasmid is removed from bacterium
Enzymes- called restrictive enzymes- are used to cut open the plasmid and cut out a gene from the DNA of another organism
A cut plasmid
New Gene
The cut ends of the plasmids and the cut ends of the new genes are chemically "sticky" so they will attach to each other - recombine - to form a new loop containing the inserted gene. This technique is called "gene splicing" or recombinant DNA technology.

FIGURE 2
Understanding the rDNA technology process is a key to learning about biotechnology.

Social/Cultural Impacts

With an understanding of what biotechnology is and the modern techniques of its applications, we will discuss how it is being used to improve our well-being. This includes work in the areas of human health care, veterinary medicine, agriculture, chemicals, waste management, and energy production.

Although the concept of biotechnology is not new, research and potential applications are in a pioneering stage. While some potentials have become reality—like artificial insulin production—it will take years of research for other potentials to be realized.

The potential for the application of biotechnology in the area of human health care is great. Current research focuses on the use of rDNA and monoclonal antibodies to detect congenital diseases, in cancer detection and treatment, to produce vaccine, in human growth and hormone studies, and to produce insulin. To date the major success in human health care has been in the laboratory production of insulin to aid in the treatment of diabetes. (Figures 3 & 4) However researchers continually study human genetic make-up to try to detect the defective genes that pass along diseases such as sickle cell anemia and other blood disorders. When identified and techniques of slicing are perfected, biotechnological methods will assist in curing these congenital diseases.

Cancer researchers are attempting to develop monoclonal antibodies that will assist in detecting cancer while in the early stages and also attack tumor cells and remove them from the human tissue.

In vaccine research, specialists are attempting to use rDNA technology to produce synthetic vaccines which do not contain active organisms that may produce harmful side effects. In the past vaccines were made from weakened viruses or bacteria. With synthetic vaccines these contaminants can be eliminated. Results have been successful in the treatment of hepatitis B. Currently researchers are working to develop synthetic vaccines for the flu, polio, cholera, herpes, diarrheal, and Rocky Mountain spotted fever.

The production of healthier livestock is the goal of veterinary medicine and its application of biotechnological means. Vaccine production has also progressed to produce medicines to protect pigs and calves against scours, and poultry from bronchitis.

Increasing the productivity of livestock is another goal of research. Studies are underway to develop cows that produce greater quantities of milk and to increase meat production in cattle, hogs, and poultry. Research findings have speculated on ways of producing hogs the size of cattle.

In the area of agriculture, work has been primarily in the area of plant production, and biological techniques have aided in crop improvement. Researchers are looking to improve yields, quality, and reduce production costs. They are doing this by applying biotechnological means to have crops produce their own defensive genes to resist disease (Figure 5). This would eliminate the costly use of pesticides.

Agricultural research is also working to develop plant strains that could live in salty or dry soil. Not all agricultural land is as rich as that in the United States. Other research seeks to modify seeds so plants will produce more lysine and tryptophan. These are the amino acids that produce the protein available in plants. If technologists can find ways to increase protein yields then the plants will become of greater nutritional value to humans and animals.

In the area of chemical production, biotechnological means are being stud-

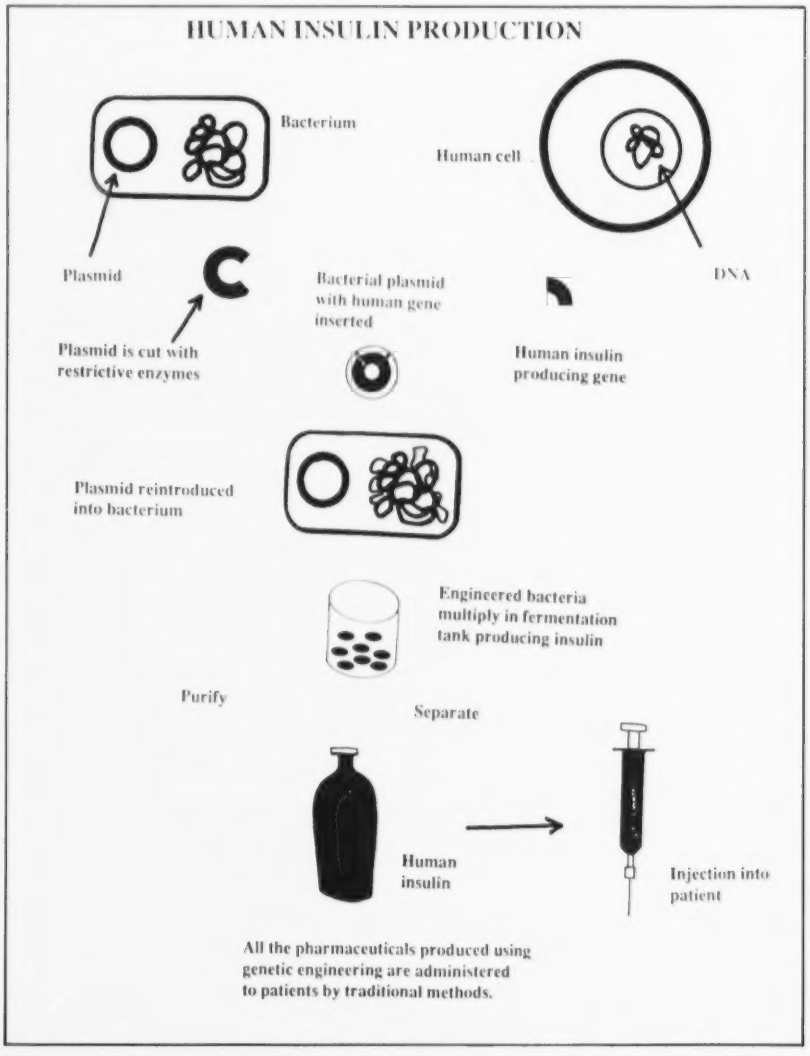


FIGURE 3
The flow of steps in artificially producing insulin.

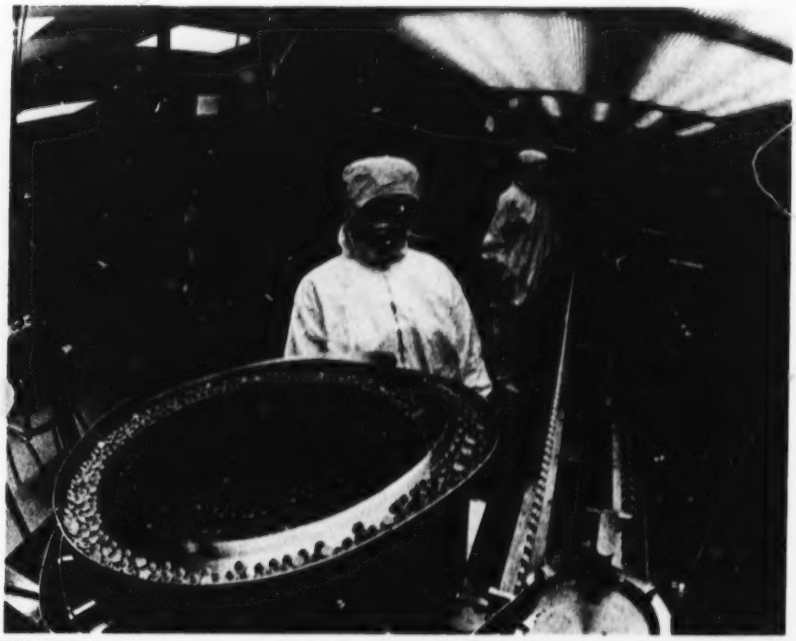


FIGURE 4
Workers package insulin in a sterile environment.

FIGURE 5
Researchers develop new chemicals to make our lives better.

ied to develop chemicals which can be used more efficiently in the production of food, cosmetic, household, and pharmaceutical products. Presently synthetic chemicals are used to produce these products. In addition to the cost of the usually needed petroleum base and the high cost of energy (high temperatures and pressures) to process synthetics, researchers feel that the use of biotechnological means will mean an improved product.

Waste management is another area where biotechnology is being used to better our environment. As mentioned earlier, degradation of solid materials is a natural process. However as more people inhabit the earth, they produce more by-products that must be disposed of. Natural decomposition takes years. Other materials do not decompose naturally in an acceptable time frame. Through the use of biotechnological methods, "waste eaters" can be produced to consume solid and wastewater products. In addition to disposing of garbage and sludge, rDNA methods are currently under study to separate ores from rocks and wastes and also to assist in retrieving petroleum from "spent" (economically pumped dry) wells.

Another application of biotechnological means is in the area of energy production. Research in this area has concentrated on the use of biomass. Through this, agricultural and forest product wastes can be broken down using rDNA enzymes. This breakdown of material produces heat that can be used for home heating or converted to energy products like methane or alcohol.

Although the research in biotechnology has produced some terrific results and there is continued hope for a better future for the human race, some people are skeptical of work in this area. They are against the synthetic development of living organisms—often because they fear the unknown.

These people point to some research efforts of the past that went sour. For example, when they were first introduced, researchers thought DDT, chlordane, EDB, dioxin, and kepone were helpful chemicals. However these chemicals have polluted rivers, ground water, and animals. Some of these chemicals have even been passed onto humans through the digestion of animal meats. And what about the numerous chemical dumps that have been created throughout the world. Some feel that biotechnology research could produce the same results.

Some feel that there is a need for tighter regulations. Others feel the creation of living organisms is against God's will. There is reason to be cautious about the creation of living organisms. If accidents occur or if testing is not conducted over a long period of time, mistakes could occur. It's frightening to speculate what might happen if synthetic living organisms harmful to human life were given time to multiply or mutate. There could be unforeseeable damage lingering well into the future.

Once Westerners visited tribal societies and brought disease with them. Some caused epidemics in the tribal world. Even the starling's introduction into North America from Europe to kill insects did not pose a problem at first. However these birds continue to multiply since their natural predators are not present in the United States. (Figure 6).

What does the future hold for biotechnology and the human race? The answers to the use of biotechnology to create new medical and industrial materials will have to wait until additional research and development are undertaken and government regulations met.

FIGURE 6
Sometimes problems result from overpopulation by wildlife.

Math/Science/Technology Interface

All of the diverse forms that life on earth takes—there are close to two million species of living organisms—might give the impression that they were the product of some joke played by a thoroughly unorganized Mother Nature. Actually, there is profound order in the entire process.

Essential to any discussion of life and genetics is the fact that all life on this earth—be it microbe or mosquito, a stand of wheat or a newborn baby—not only has the ability to reproduce itself but is made up of cells. And these cells all contain genes, the units responsible for inheritance—with each gene made up of the same wondrous chemical. This chemical is DNA, short for deoxyribonucleic acid.

But let's back up a moment to the time of an Austrian monk, Gregor Mendel—about 100 years ago. Before DNA was known, Mendel first demonstrated experimentally the phenomenon we know as genetic inheritance. This is a central scientific principle involved in genetic engineering. It is through this mechanism that various characteristics are passed along from one generation to another.

Mendel is best known for his work with the common garden peas. What he did was to grow many generations of pea plants, using seeds of each generation. Beginning with purebred plants—those grown from a recognized strain and not mixed with any others—he observed that their seeds always produced plants with similar traits, one generation after the other. Seeds from red-flowered, purebred pea plants, for instance, invariably brought forth red-flowered plants. Later it was discovered that the code that carries these traits is contained in the DNA molecule (Figure 7).

Exactly how does a cell's machinery "read" the genetic instructions in DNA, and use them to produce exact replicas of itself again and again and again. Just what is this code, this formula for life? How is it used to make the proteins, which are the building blocks of cells in living things.

If we examine a chromosome closely, we see that it is sectioned into genes that are made up of very long, slender molecules of two-stranded DNA, twisted together and wound around an inner core of protein. Every human cell has twenty-three pairs of DNA strands, corresponding with the number of chromosomes from each of our two parents.

If we could stretch out a single cell's DNA molecule, they would stretch several feet, many thousands of times the width of the cell itself. It would be well to pause here for a moment and reflect on the incredibly tiny world with which we are dealing.

The structure of the DNA is in a double helix form, made up of twisted strands of DNA. There are more than 10 billion miles of it in the total number of cells in an adult human body, yet it is so compact that all of it would fit easily into the space a wrist watch occupies (Figure 8). First, let's take a close look at the twisted chemical ladder itself. A chemist would find no unfamiliar substances among its various parts, which are called nucleotides. The spiral sides of the ladder are phosphates, which are combinations of the mineral phosphorus and oxygen, and sugars. The rungs are made up of four chemical molecules—adenine, guanine, cytosine, and thymine. (A, G, C, and T).

Each rung actually consists of two of the chemicals, joined in the middle. For example, a half-rung of C always joins with a half-rung of G to form a whole rung; an A always ties into a T. These rungs are grouped in four letter codes. The order of these four letter chemical codes transfers the information that the life-form will take, and gives each gene its own special coded orders to direct the manufacture of the protein for which it is responsible.

The action begins when the DNA ladder unwinds and the rungs pull apart in the middle, a process that occurs every time a cell begins its ritual of dividing, all of the Cs unhook from the Gs, the Ts from the As.

But soon each freed side of the ladder with its half-rungs picks up new nucleotides that are always floating about in the cell. The Cs, Gs, Ts, and As on the ladder halves link up with their proper floating partners and the new ladder sides are formed. Now, where there was one twisted ladder there are two, identical in every aspect. Each time a cell dupli-

cates itself, so does its DNA.

The next step for the cell is to use the instructions coded in the genes. It does this much like an architect drawing blueprints for a construction engineer. The blueprints, in this case the genes, contain the coded instructions for making a specific protein. What happens is this: a section of DNA in a gene "unzips" itself again and makes another nucleic acid called messenger RNA, or mRNA. In doing so, the gene hands over to the messenger the entire coded blueprint for one protein.

This completed, it zips itself up once again. The messenger now moves out of the nucleus into the cell's cytoplasm, carrying its instructions to the ribosomes (protein factories). There the messenger RNA acts as a computer program to use amino acids to make the designated protein.

Another form of RNA now enters the picture. This form, of great importance to the genetic engineer, is called transfer RNA, or tRNA.

It takes the instructions and floats out into the cytoplasm to hunt down the amino acids called for in the triplet code. After linking up with the right amino acid, the transfer RNA takes it to the ribosomes where, with the help of the mRNA, a protein with a special function is formed.

With this overview of the genetic structure of DNA and RNA we are now able to better understand the link between biotechnological changes and the role of the cell's vital function in the reconstruction of our natural environment.

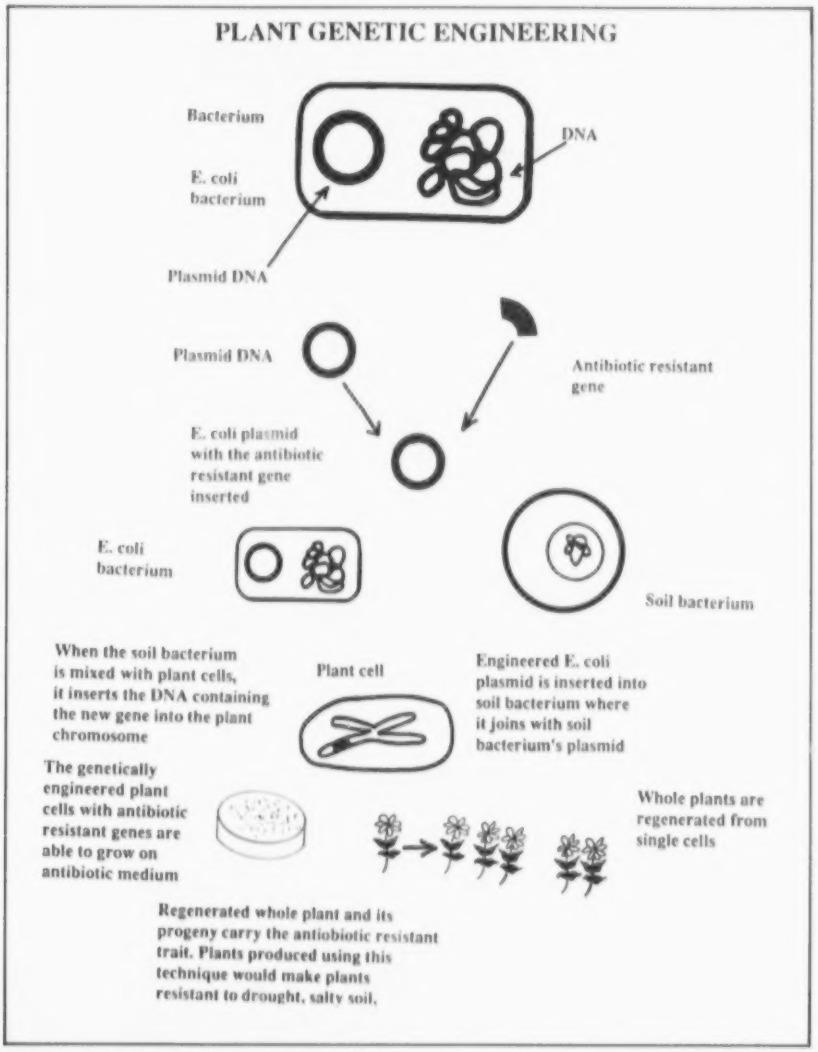

PLANT GENETIC ENGINEERING
Bacterium
DNA
E. coli bacterium
Plasmid DNA
Plasmid DNA
Antibiotic resistant gene
E. coli plasmid with the antibiotic resistant gene inserted
E. coli bacterium
Soil bacterium
When the soil bacterium is mixed with plant cells, it inserts the DNA containing the new gene into the plant chromosome
Plant cell
Engineered E. coli plasmid is inserted into soil bacterium where it joins with soil bacterium's plasmid
The genetically engineered plant cells with antibiotic resistant genes are able to grow on antibiotic medium
Whole plants are regenerated from single cells
Regenerated whole plant and its progeny carry the antiobiotic resistant trait. Plants produced using this technique would make plants resistant to drought, salty soil,

FIGURE
Plant genetic engineering.

Constructional Activity

Experiments in genetic engineering can be quite interesting. However, many of them involve materials that are not easily available and are difficult to handle. Several scientific houses offer prepackaged kits that illustrate genetic engineering and biotechnological principles clearly and economically. For example, Frey Scientific offers a kit that can be used to create new strains of bacteria that are resistant to antibiotics. With another kit you can study the differences between DNA and RNA.

In the field of biotechnology several experimental kits are available to explore enzymes in industry (such as food and drink processing, organic synthesis of amino acids and antibiotics, and in leather production), enzymes in the home (such as food flavor enhancement, removal of stains, tenderization of meats), and others involving textiles, paper production, and chemical processing.

For details look under the headings of "genetics" and "biotechnology." The Frey Scientific catalog may be obtained fromFrey Scientific Company, 905 Hickory Lane, Mansfield, Ohio 44905; 800/225-FREY.

Summary

Although biotechnology has been used for centuries, its contemporary uses are much more far reaching than past applications. The alteration of human and animal life poses many questions. Will biotechnological methods be safe and lead to more meaning lives? The answer to this and other questions are just over the horizon.

If properly used, this technology can provide more food to the world's population and cure many of our fatal diseases. Time and governmental regulations, in addition to research expenditures and breakthroughs, will eventually show what lies ahead in the technological area of biotechnology.

Biotechnology is in a pioneering stage; there are few laws that govern the many facets of experimenting and creating living organisms. Many legal, medical, and research questions have been raised and will continue to be raised as researchers explore the living world beyond which we can see. There are however, many laws and regulations that regulate experimentation and research on human subjects. Many ethical issues will be debated which extend beyond what we know as laws and into moral, philosophical, and societal values.

FIGURE 8
Scientists use models to help them understand the structure of nature.

New Terms

Antibody—Protein of an animal immune system that is produced in reaction to the presence of a specific antigen.
Amino acids—Amino acids are the basic building blocks of proteins. There are twenty amino acids that join together to form proteins.
Antigen—A substance that causes the production of specific antibodies that cause an immune response by an animal.
Biotechnology—A broad area that combines technology and biological processes or procedures to manufacture products.
Bioprocessing—A process where living cells or their parts are used to design and produce an end product.
Chromosome—One or more small rod-shaped elements in the nucleus of a cell that contain genetic information for that cell. It is also a collection of genes.
Clone—A group of organisms, genes, or cells that are produced from a common ancestor. When cloning cells and organisms, there is no combining of genetic material as is sexual reproduction. Thus, the members of the clone are genetically identical to the parent material.
DNA—Deoxyribonucleic acid is the molecule that carries the genetic information for most living systems. The DNA molecule consists of four nitrogen bases, adenine (A), thymine (T), guanine(G), and cytosine (C), and a sugar-phosphate backbone that is arranged in two strands to form a double helix.
Enzyme—A protein that promotes specific chemical or metabolic reactions that are necessary for cell growth and reproduction.
Escherichia coli—Commonly called E. Coli, this is a bacterium that is found in the human digestive tract. It is used in much of the work done in rDNA research because it has been genetically well characterized.
Fermentation—A process of growing microorganisms for the production of various chemical or pharmaceutical compounds. Microbes are usually incubated under specific conditions in a nutrient medium in large tanks called fermenters.
Gene—A segment of a chromosome that directs the synthesis of a protein.
Gene splicing—The technique of inserting new genetic information in a plasmid. The same as recombinant DNA.
Hybrid—The offspring or production of cells, organisms, or plants form genetically different parents. This process can

be used to produce hybrid plants by crossbreeding two different varieties. Also hybridomas can be formed by fusing two different cells that are used for producing monoclonal antibodies.

Monoclonal antibody—A highly specific purified antibody that is produced from only one clone of cells that recognizes only one type of antigen.

Ligase—An enzyme that is used to splice DNA segments together.

Microorganism—A very small organism that can only be seen with the aid of a microscope.

Mutation—The alteration of a gene.

Plasma— The blood component that remains after all of the cells have been removed but includes the clotting factors.

Plasmid—A circular piece of DNA that is found outside the chromosome in bacteria. Plasmids are the principal tool for inserting new genetic information into microorganisms or plants.

Polycolonal—A specific purified antibody that is produced from one clone of a cells that are recognized by several types of antigens.

Recombinant DNA (rDNA)—The hybrid DNA that is formed by combining pieces of DNA form different types of organisms.

Possible Student Activities

1. Define biotechnology.
2. Explain the areas in which biotechnology are used.
3. Describe products that are produced through biotechnological means.
4. Evaluate ethical issues that are related to biotechnology.
5. Describe the structure and function of DNA, rDNA, and RNA molecules.
6. Experiment with selected biotechnology laboratory projects.

Student Quiz

1. Describe the term biotechnology.
2. Explain the use of bioprocessing technology.
3. Outline the steps in rDNA technology.
4. List five uses of products that use monoclonal antibodies.
5. Describe examples where biotechnology could possibly cause harm to humans and the environment.
6. Identify the four amino acids found in DNA.
7. List five benefits of biotechnology to society.
8. What is the difference between a clone and a sexually produced offspring?
9. Identify several careers that are related to biotechnology?
10. What bacterium is most commonly used in biotechnology research?

References

Amgen Corporation. General materials. Thousand Oaks, CA: Amgen Corporation. (Available from: Amgen Corporation, 1900 Oak Terrace Lane, Thousand Oaks, CA. 91320).

Industrial Biotechnology Association. (1986). *What is Biotechnology?* Washington, DC: Author.

Monsanto Chemical. *Genetic Engineering and Natural Science*. Glen Gardner, NJ: Author.

Eisman, L. & Tanzer, C. (1983). Biology and human progress (4th edition). New York: Prentice-Hall.

Weiss, R. Of judges, genes and genetic engineers. *Science News, 132*, 124-125.

Editor's Note: The September 1987 edition of The American Biology Teacher *(Volume 9, Number 6) carried an article, "Does Biotechnology Have a Place in Introductory Biology?," to help biology teachers gain the background they need to teach biotechnology. You might see if your school's biology teacher is a member of this association and borrow her/his copy.*

Among the hints offered by the article is suggesting instructors write biotechnology for copies of product brochures and investor reports which generally contain descriptions and illustrations that can be used in the classroom. You might try this too! The firms listed:

Applied Biosystems, Inc.
850 Lincoln Center Drive
Foster City, CA 94404

BioResponse, Inc.
550 Ridgefield Road
Wilton, CT 06897

Cytogen Corporation
201 College Road, East
Princeton, NJ 08540

Endotronics
PO Box 32366
Minneapolis, MN 55432

Genetic Systems
3005 First Avenue
Seattle, WA 98121

Molecular Genetics, Inc.
10320 Bren Road, East
Minnetonka, MN 55343

Agrigenetics Corporation
3375 Mitchell Land
Boulder, CO 80301

Cetus Corporation
3400 West Bayshore Road
Palo Alto, CA 94303

Genentech, Inc.
460 Point San Bruno Blvd.
South San Francisco, CA 94080

Genex Corporation
12300 Washington Avenue
Rockville, MD 20852

Resources in Technology

Polymeric Materials

This instructional module builds on a series that began with "New Materials" (Resources in Technology, Volume 3). You may find it useful to re-read that module as well as "Nature & Properties of Engineering Materials" (Resources in Technology, Volume 4) prior to studying this module.

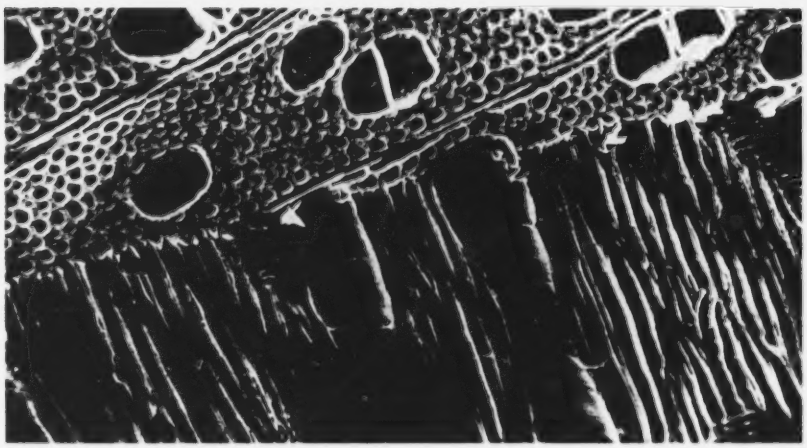


FIGURE 1
The complex structure of wood results from cellulose polymer which can be seen in figure 5. Another polymer, lignin bonds the fibers together. Shown here at about 100 times magnification a section of wood shows cell openings.

Polymers are as old as life and as new as tomorrow. Simple plants are natural polymers such as the mold that grows on stale bread or cheese. Complex plants are composed of many polymers. Trees are made-up of cellulose fiber polymers held together by a glue-like fiber—polymer lignin. Tree fibers are very complex natural polymer structures in the form of roots, trunks, branches, and leaves. Figure 1 shows the internal structure of wood from a tree.

Polymer chemists make new synthetic polymers nearly every day in attempts to provide useful products. Among these "manmade polymers" are new paints, food products and additives, medicine and artificial skin, plastic resins, new adhesives, lubricants, and synthetic rubbers.

This module provides a brief look at some industrial polymers. But it cannot begin to address what is an almost infinite variety of polymers—polymers that range from those in your body (natural hair, bones and skin), to the many synthetic polymers used throughout our lives for food (phenylalanine in Nutra-Sweet™), clothing (polyester blends), shelter (vinyl siding) and recreation (polyurethane skateboard wheels). Hopefully, this "Resources in Technology" will whet your appetite to learn more about polymers through study of the references listed at the end of this module.

Social/Cultural Impacts

An article published May 25, 1987 in *Newsweek*, (pp. 73-74), declared " . . . the world will seem be made of new materials" and it drew a parallel between the Stone Age and Iron Age with the emergence of "The Age of Superstuff" in which they described the products coming to society from materials science. High technology research and development efforts in Japan, Europe, and the U.S.A. are spewing forth a wide range of superstuff (new materials) that vary from "high temperature" superconductors to diamond and other thin ceramic films, new metal alloys, rapid solidification/amorphous metals in addition to a wide range of exotic polymers and composites. It is hard to imagine what changes these innovations will produce by the next century.

Much of the work involving new materials comes from the " . . . researcher's ability to manipulate substances at the molecular level" (Rogers, 1987). Figure 2 shows a number of hydrocarbon molecules (combinations of atoms) and polymers that exist or are synthesized from only hydrogen and carbon. Methods of bioengineering point to the creation of million of new polymers. How the organic and inorganic polymers are combined into new materials will determine the properties of the new materials. Most new materials carry the possibility of both benefit and harm to society.

Scientific and political leadership must learn how to monitor polymer and materials research and development in order to have policies that insure the public good. Citizens must be knowledgeable of the issues surrounding materials science and engineering materials technology to protect themselves in selection of their leadership.

It is imperative nations that wish to gain or maintain a high standard of living produce world class products that compete favorably in the world market. But it is also important to protect the environment and health of a nation's people through wise legislation and safety conscious practices.

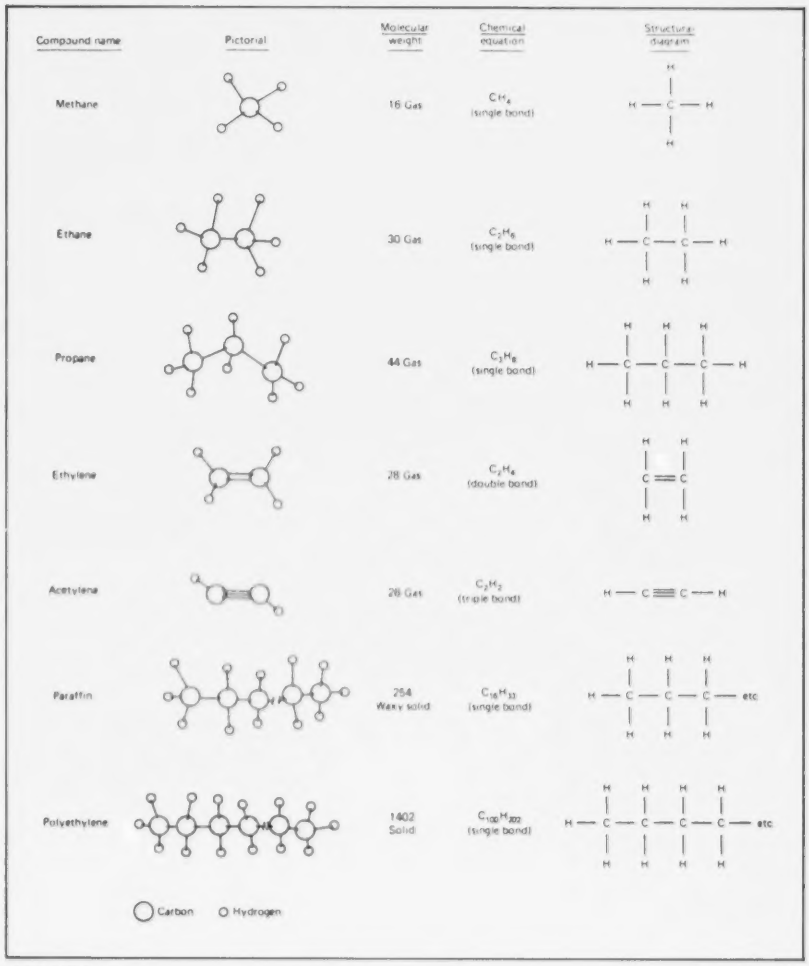


FIGURE 2
Hydrocarbons of the methane gas series show an increase of molecular weight (top to bottom) with an increase in atoms and change from gas to liquid to solid. Molecules are forced together in synthesis to form polymers.

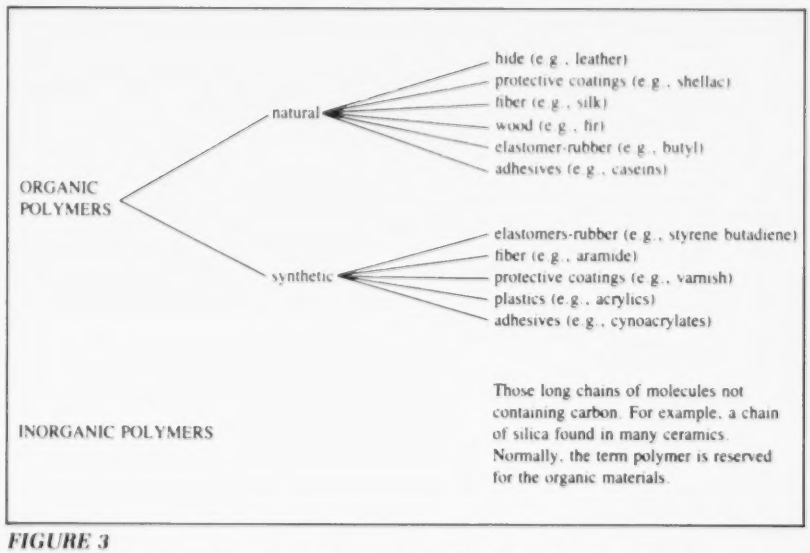

ORGANIC POLYMERS
natural
hide (e.g., leather)
protective coatings (e.g., shellac)
fiber (e.g., silk)
wood (e.g., fir)
elastomer-rubber (e.g., butyl)
adhesives (e.g., caseins)
synthetic
elastomers-rubber (e.g., styrene butadiene)
fiber (e.g., aramide)
protective coatings (e.g., varnish)
plastics (e.g., acrylics)
adhesives (e.g., cynoacrylates)
INORGANIC POLYMERS
Those long chains of molecules not containing carbon. For example, a chain of silica found in many ceramics. Normally, the term polymer is reserved for the organic materials.

FIGURE 3
Industrial polymers are a major grouping of the family of materials. Generally, a reference to polymeric materials means organic polymers.

Nature and Properties of Industrial Polymers

Figure 3 depicts two subgroups (natural and synthetic) of organic industrial fibers that form one major family of engineering materials. The other family groups are metals, ceramics and composites. Among the natural organic polymers is hide or skin of animals that is used to make leather shoes and handbags; another is wood such as red oak used in furniture making. These polymers occur in nature and can be made into useful products often without extensive processing; for example, sawing up trees to produce boards for lumber.

Some natural elastomers such as isoprene must undergo extensive processing in order to become raw materials as they embark on the path to becoming part of a finished product (Figure 4). On the other hand, synthetic polymers usually require extensive chemical processing of naturally occurring raw materials including mineral or vegetable oil, cotton, animal blood, urine or milk before they can be made into useful forms such as liquid resin, sheet, tube or bar stock for making finished parts.

Elastomers/Rubbers

One source of latex for natural rubber processing in the Hevea Brasiliensis tree. After extraction, the latex liquid is dried to form polyisoprene rubber which may be blended with synthetic rubber to achieve desired properties. Figure 4 also shows the further processing rubber goes through with other materials to produce tires. The tire that is produced also incorporates a synthetic rubber such as EPDM (ethylene propylene) to create sidewalls that withstand flexing and weathering without crazing. Many other rubbers, both natural and synthetic, may be blended into the tire.

Addition of sulfur to natural rubber vulcanizes the rubber which makes it a thermosetting polymer. The vulcanized rubber will not oxidize easily nor combine with solvents such as gasoline and oil. Rubber, after vulcanizing, Figure 6 has formed covalent bonds between the carbon and sulfur at active sites where double bonds exist. If these double bond sites were allowed to exist unaltered, the rubber would more easily "dry rot" or dissolve through contact with hydrocarbon solvents such as oil or gasoline.

Wood

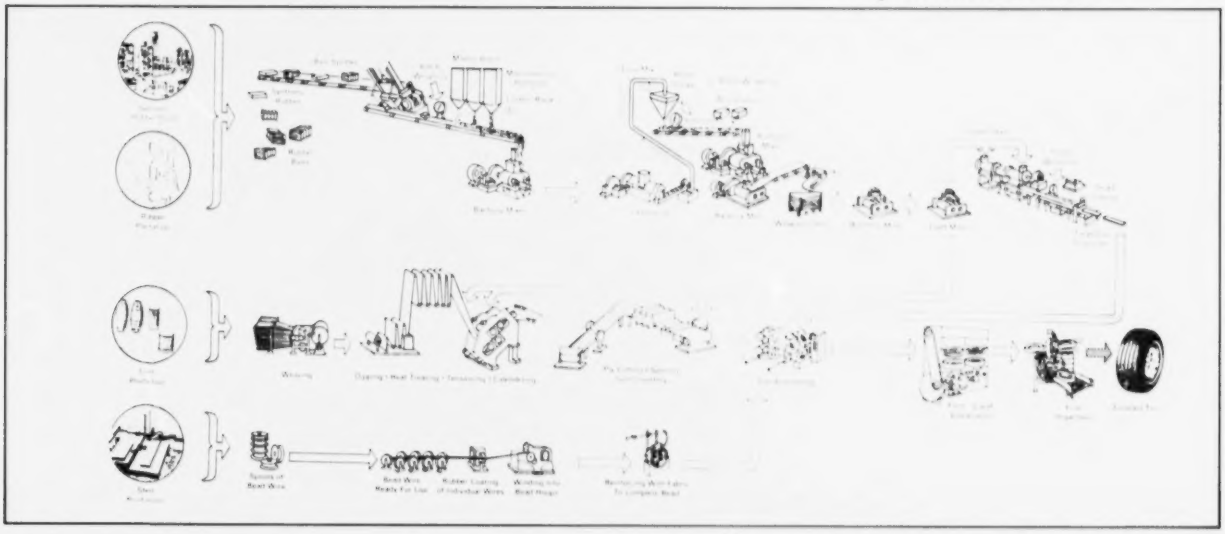
One of the longest used engineering materials is gained through harvesting of trees. Among the many advantages offered by wood is the fact that wood is a renewable resource. That means that we can continue to plant and harvest this raw material for a source of an important engineering material. On the other hand, oil for plastic and rubber, ores for iron and chromium plus natural gas for plastic and paint are nonrenewable. Once they are extracted from the earth we cannot replace them, but instead we must wait millions of years for them to reform.

Figure 5 shows a sketch of a wood fiber many times its actual size. Cellulose fibers (left) are very complex polymers. They are bonded together with other fibers by the polymer lignin. Within the fiber (top right) are a series of layers known as fibrils which have different orientation. A large fibril angle (bottom center) normally yields wood of less strength than a small fibril angle (bottom left). Lignin serves as a matrix to not only bond the cellulose fibers but also to fill the space between fibers.

The structure of wood has been imitated by materials engineers who specialize in composite structures. These materials engineers use glass or synthetic fibers that are oriented at different angles in such a manner as to reinforce polymer or metal matrices which are engineered composite materials. Because of the different orientation of the fibers, wood has anisotropic (unequal directional) properties.

Figure 6 shows Alaska yellow cedar with end grain (top), quarter sawn grain (middle) and plain sawn grain (bottom). The grain patterns reveal that orientation of fibers determines such strength properties as shear, flexural, or tensile strength. On the other hand, if you examine cast materials that have uniform structure such as cast plastic, metal or glass, you can understand how the materials possess isotropic properties:

FIGURE 4
This diagram shows how natural rubber is compounded with synthetic rubber and other additives then joined together with cord and steel then vulcanized to produce a composite material tire.



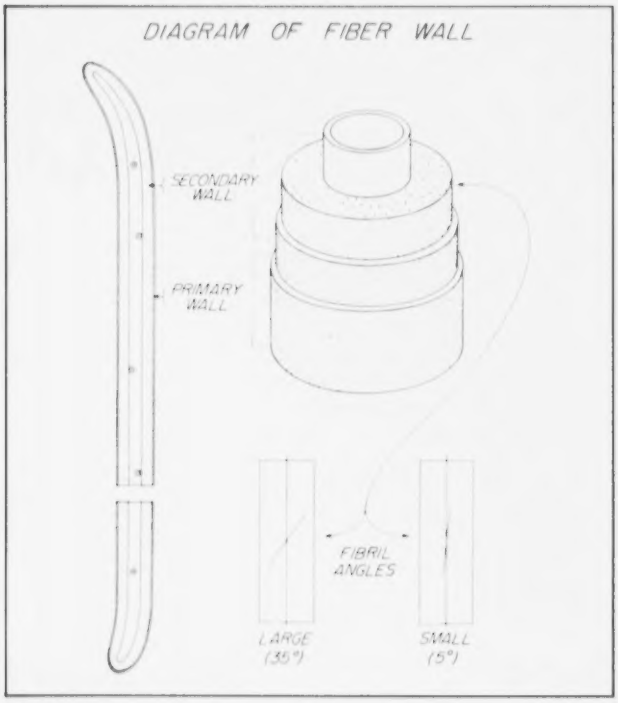


FIGURE 5
The wall of the wood fiber is a complex tubelike structure that combine to form anisotropic properties.

FIGURE 6
Wood grain and color imparts warmth and beauty through its appearance. Attempts to duplicate wood is often tried by materials engineers sometime with good success.

the strength is the same in all directions.

Wood possesses many valuable properties. Figure 6 shows the physical properties of appearance gained from the wood's natural color, grain structure plus effects of how the tree is sawed. Other physical properties result from moisture content of the tree and the wood after it is treated.

Structure also affects the density of the wood. Hardwood trees are normally more dense than softwood trees, but there are many exceptions. For example, basswood and balsawood are hardwoods which are both lighter in weight and softer than most softwoods. Basswood is used for drafting boards and balsa for model airplanes. Yellow pine, a softwood, can be quite heavy and is hard enough to make floors for homes.

Wood also has ablative properties: when the top layer burns it can protect the inner layers which are slower to burn because the charred outer layer prevents oxygen from reaching the inner layer. When trees are made into firewood you must split them into smaller pieces for good burning. If you don't, once the outer part of the log is charred the log will not burn as well. If you knock off the charred layer then the wood exposed to the air will ignite easily.

This principle was used with the spacecraft of the era before the reusable Space Shuttles. An ablative heat shield made of a nylon/phenolic plastic polymer was attached to the space capsule. When the capsule reentered the earth's atmosphere with the heat shield first, it encountered friction causing the polymer shield to burn at a controlled rate because of the protection from the charred outer layer on the polymer shield.

This property is important for slowing the burning of a wooden structure. Steel on the other hand will not easily burn, but will hold heat and deform if sufficient heat is allowed to accumulate. Of course, wood does not possess mechanical properties on par with steel; it is not as hard and possesses only a fraction of the stiffness and tensile strength.

Plastic

This is the largest group of synthetic polymers used for engineering materials and also the largest group of general purpose polymer materials. Engineering plastics are those plastics which have sufficiently favorable properties to compete with the traditional engineering materials such as wood, steel, brass, cast iron, concrete, stone, and brick. General purpose plastics are other plastics which may be used for a wide range of applications where the ability to bear heavy loads or resist high temperatures is not the major concern.

One application of a new polyarylate thermoplastic from duPont known as Arylon™ is in the internal gear drives and timing mechanism of the control timer wheel for kitchen ranges. These mechanisms are made of this new polyarylate resin because of the plastic's strength, stiffness, and thermal and dimensional stability.

A report in *U.S. News and World Report* (December 29, 1986/January 5, 1987, pp. 88-89) told of duPont's wonder plastic, Arylon™ "... tougher than any polymer yet produced ... won't expand or shrink; shrugs off heat, flame, harsh chemicals and electric jolts; won't weather, and is as strong as some kinds of steel ... tolerates temperature up to 3,000° F ... under $2.00 a pound compared with $2.80 a pound for conventional polyarylates."

This super plastic can be used for housings on refrigerators and microwave ovens, golf club shafts and printed-circuit boards in supercomputers. It will

not dent like aluminum nor rust like steel and can be used for rupture proof toothpaste tubes and bags for potato-chips that will not admit light nor moisture.

Cellular or foamed plastic and fiber reinforced plastics (FRP) may also be engineering plastics. These plastics have cells (hollow spherical voids) in the plastic as a result of a gas used in the forming of the parts or by mixing hollow glass or plastic spheres into the resin.

The air voids provide a number of benefits to the cellular plastics; lighter weight with increased bulk, excellent thermal insulation, good shock absorption (impact strength), and improved strength-to-weight ration (specific strength). You can see the spherical voids in cellular plastic by breaking apart Styrofoam™ (foamed polystyrene) packing material, and observing noting the hollow spheres. Uses of cellular foam polymers (plastics and elastomers) include

- Polystyrene foams for insulation in building construction, Thermos™ bottles, and appliances, and packing material
- Cellular polyethylene for electrical wire insulation
- Polyimide foam for high heat resistance for aircraft
- Epoxy foams for flotation devices
- Cellular silicone for electrical and electronic encapsulation, chemical resistant fillers and structural insulation
- Reaction injection molding (RIM)
- Cellular polyurethane with reinforcing fibers for auto hoods, doors and seat frames
- Syntactic glass-filled foams of polyester for tennis racquets, bowling balls, helmets, and skateboards.

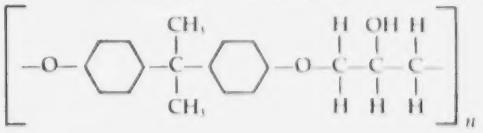
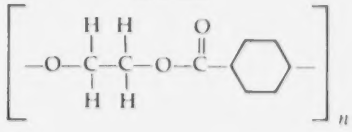
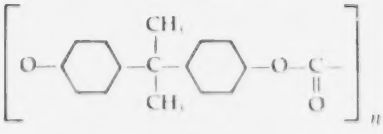
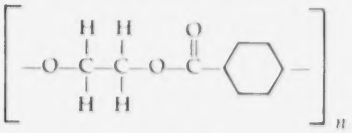
These are but a few examples. We do not go into much discussion on glass or fiber reinforced plastic (GRP or FRP) because these are given more treatment in the module on composites.

To gain an appreciation for the wide range of structures and properties of plastics, two tables are presented from *Engineering Materials Technology*. Figure 7 shows a some representative plastics (Jacobs & Kilduff, p. 450) and presents common (chemical) names, American Society for Testing Materials (ASTM) abbreviations, common chemical structures, classification grouping (TP thermoplastic, TS—thermosetting, EP-engineering plastic) and some typical uses of those plastics. Next, Figure 8 provides another comparison to depict the ranges of tensile strength at room temperature for selected plastics compared to other materials (Jacobs & Kilduff, p. 252).

Adhesives

This group of polymers is growing in its importance. So too are the number of available polymer adhesives growing. Not all cementitious materials (adhesive) are organic polymers. Inorganic materials in the form of ceramic materials that have adhesive properties include lime, gypsum and pozzolans. Portland cement is the ceramic adhesive most common to the average person. To use glues, there must be compatibility between an adhesive and materials it is

FIGURE 7
Representative plastics

Common name (chemical name)	ASTM Abbreviations	Trade names	Common structure	Grouping*	Typical uses
Phenoxy (polyhydroxyethers)			Amorphous or crosslinked network 	TP, TS, EP	Gas pipe, sports equipment, electrical housing, adhesives and coatings
Phenylene oxide (polyphenylene oxide)	PPO	Noryl	Crystalline 	TP, EP	Auto trim, panels, electrical housing, TV cabinets, pump parts
Polycarbonate	PC	Lexan	Amorphous 	TP, EP	Optical lenses, bullet resistant windows, housings and cookers
Polyester (polyethylene terephthalate) (polybutylene terephthalate) (aromatic polyesters)	PET (TS) PBT (TP)	Mylar Dacron Kodel Fortrel Laminac Selectron Gafite tp Ekonol	Amorphous or crosslinked network 	TS, TP, GP, EP	Glass fiber reinforcer, films, fibers

intended to bond together.

Much of the problem encountered with incompatibility of adhesive with adherents and substrates is due to chemical interactions. Figure 9 depicts one of the necessary conditions for adhesion to occur, namely wetting.

For good wetting of adhesive to a substrate (surface making the bond) or adherent (material to be bonded), there must be a free spreading of the adhesive film over the surfaces and into microscopic hills and valleys. Poor wetting happens when the adhesive beads up like water on a ducks back or a freshly waxed car. The reasons for good and poor wetting involve concepts of surface tension, viscosity and other factors which are beyond the scope of this module.

Beyond wetting, many other events must occur for proper bonding. Not all is completely understood about an adhesively-bonded joint. However, among the known factors, proper joint preparation is certainly crucial and usually includes clean surfaces and maximum surface area for adhesive to adherent contact. In addition to understanding the bond linkages, there are factors to take into account when selecting adhesives.

Figure 10, "Common Adhesives" taken from *Engineering Materials Technology* (Jacobs & Kilduff, p. 297), provides a comparison of some frequently used adhesives, indicating adherents that the adhesive should bond with and examples of some uses of the adhesive/adherent systems.

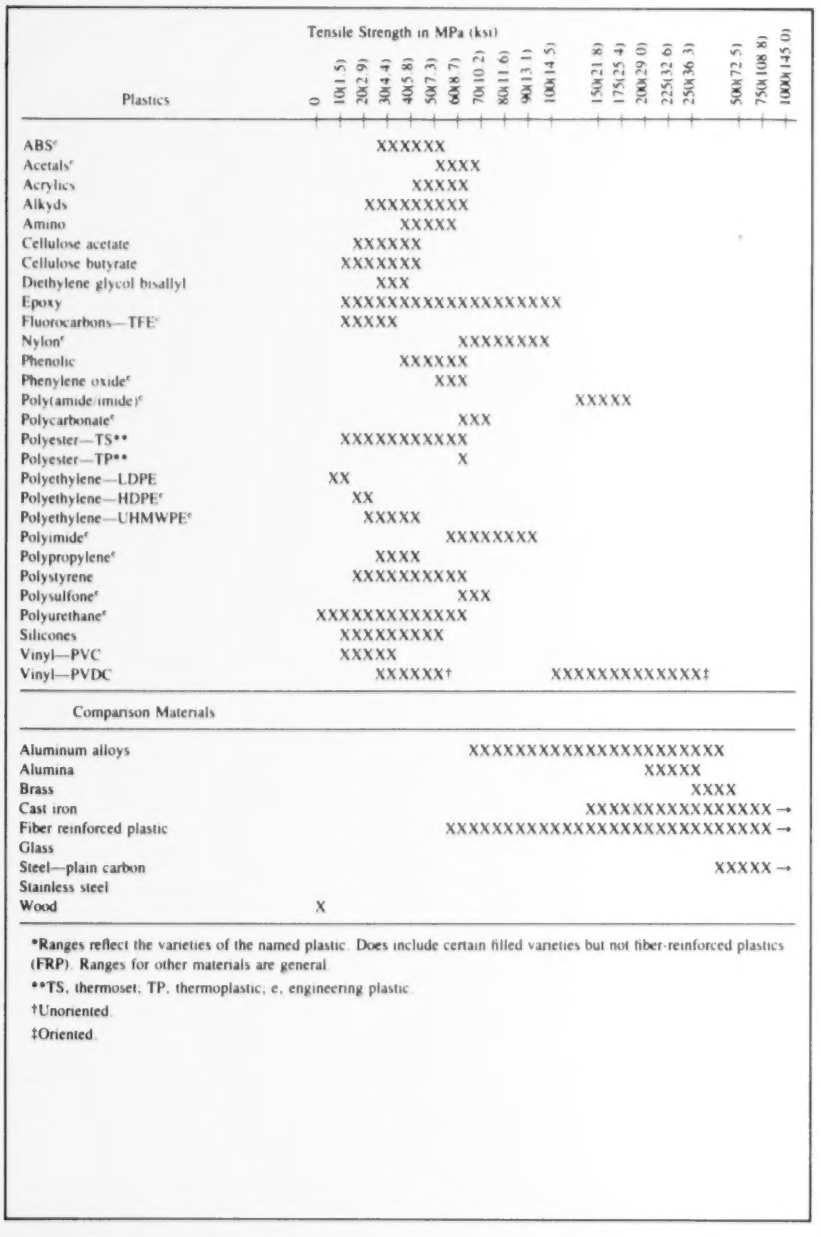
Your best approach to selection of adhesives is to use guides such as Figure 10 which provides general rules, then look for more specific guidelines such as the manufacturer's specifications and the instructions printed on the adhesive packaging.

"Industrial Adhesives Start to Spread" in *High Technology* (Heppenheimer, June, 1987, pp. 56-57) provides an insight into industrial technology's use of gluing. Automated application of adhesives and sealants involves robots and is very much a part of auto-making. Automotive service manuals provide instructions on testing polymers to determine the proper adhesives and automakers are placing markings on the polymers in cars and trucks.

Heppenheimer reported on a pickup truck that crashed at 20 mph into an adhesively bonded golf cart; the truck required $2,000 for damage repair while the golf cart received minor damage and was easier to repair. This is because adhesive bonding provides load spreading over an entire panel or joint thus producing lighter and stronger components.

With more designers recognizing the many advantages offered by adhesives, wide spread use of them is being seen. The construction industry is replacing nailing and other mechanical fasteners with adhesives. That same magazine article went on to report that 100 companies are offering over 25,000 different types of adhesives. However, in manufacturing only five classifications of glues serve 95% of the needs. The adhesives are:

- Epoxy
- Urethane
- Acrylic
- Anaerobic
- Cyanoacrylic



*Ranges reflect the varieties of the named plastic. Does include certain filled varieties but not fiber-reinforced plastics (FRP). Ranges for other materials are general.

**TS, thermoset; TP, thermoplastic; e, engineering plastic.

†Unoriented.

‡Oriented.

FIGURE 8
The range of tensile strength at room temperature for selected plastics compared to other materials.

Protective Coatings

Many of the names for plastic and elastomeric polymers are also used with protective coatings. These include epoxy, urethane, acrylic, latex and silicones. In the class of a natural polymers, shellac is used in wood finishing, while oil-based

paints protect many materials. Just as with adhesives, there is a concern about protective coatings composed of highly volatile solvents that create fire and health hazards.

There is a movement to eliminate the hazardous solvents which are necessary to liquefy certain polymers. In this movement polymer chemists are seeking means to develop reliable water-based products for adhesives and protective coatings.

Oils, lubricants, fluids for hydraulics and cooling, and polymer conductors are some other subgroups of polymers that can be investigated. There are many exciting research, development and application activities related to these polymers which may have significant impact on our lives.

M/S/T Interface

A study of the structure of atoms, atomic bonding and the Periodic Table of Elements through general science and chemistry courses introduce aspects of organic chemistry and serve as a small entree into polymer chemistry. A career in materials science would involve these types of study as would career preparation to become a polymer chemist.

But a general knowledge of chemistry is necessary for all intelligent people to help them become wiser consumers and informed citizens. Engineers, technicians, technologists, and craftspeople will encounter reading and other forms of communication in their jobs which require a knowledge of polymers. Therefore they should have an introduction to these aspects of chemistry.

For a brief exercise, locate a Periodic Table of the Elements and use it to determine the composition of the elements shown in Figure 7 (which gives some common structures of a few plastics). You will note that of the hundreds of plastics, only a handful of elements are necessary for their synthesis. Carbon serves as the backbone for nearly all of them and hydrogen is also present with carbon in all plastics, so they are labeled hydrocarbons.

But there are usually exceptions to most rules. Locate a reference such as *Engineering Materials Technology* to look at the diagrammed structure of silicone plastic to note the backbone.

Construction Activity

Polymer products are found everywhere. This "Resource in Technology" has increased your awareness of many forms of polymeric materials. To construct an attractive display do the following:

- Locate 8 to 12 sample polymeric materials being sure to obtain a couple of samples from each subgroup: thermosetting plastics and thermoplastic plastics, cellular plastics, elastomers, adhesives, protective coatings and wood.
- Determine the type of polymer you have. This can be very difficult but there are some tests which can be used to make an educated guess about plastics and rubbers. These tests are given in repair manuals for newer model cars and some books on plastics *Caution*—Carefully follow rules for ventilation and other safety instructions.
- Obtain a brightly colored piece of posterboard measuring 215mm × 279mm (about 8.5 in × 11 in);
- Use typing paper to make labels to mount on the posterboard with a large

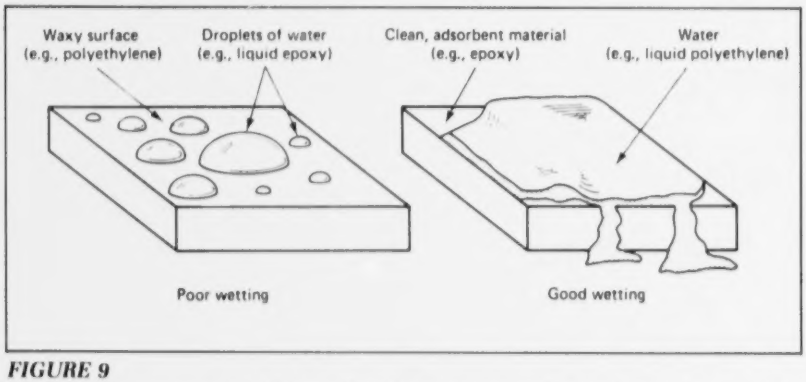


FIGURE 9
Wetting is a concern in adhesive bonding. Poor wetting will cause the glue to bead up on the substrate rather than cover the entire surface. Good wetting provides uniform load spreading when the adhesive cures.

Adhesive	Typical adherends and applications
Acrylics (2 part)	Plastics (ABS, phenolic-melamine, polyester, polystyrene, polysulfone, PVC) to metal, rubber to metal, and plastics to plastics
Casein	Interior wood components
Cyanoacrylates (anaerobic)	Thread locking, gear and bushing mounting, aluminum, copper, steel, ceramics, glass, rubber, polycarbonate, phenolic, acrylics
Epoxy	Most adherends except some plastics such as acetals, polypropylenes, polyurethanes, and silicones; many modifications including nylon epoxies and epoxy phenolics
Melamine formaldehyde	Paper, textiles, hardwood, plywood for interior use
Natural rubber	Cork, foam rubber, leather, paper-building materials, pressure-sensitive tapes
Neoprene rubber	Many plastics (ABS, fluorocarbons, polystyrene), aluminum, ceramics, copper gasketing and laminating
Nitrile rubber and phenolic	Many plastics (ABS, cellulose, fluorocarbons, PVC, polyester), aluminum, ceramics, glass, magnesium, microwave isolators
Phenol-formaldehyde	Cork, cardboard, softwood, plywood for exterior use
Polyvinyl acetate	Textiles, polystyrene, wood, other porous and semiporous materials, interior furniture and construction
Resorcinol-formaldehyde	Asbestos, cork, paper, rubber, wood furniture, laminated exterior wooden beams, wooden boats
Silicone	Aluminum, ceramics, glass, magnesium, phenolics, polyester, acrylics, rubber, steel, textiles, integrated circuits, sealants, gasketing
Urethane elastomer	Many plastics (ABS, polyester, acrylics, PVC), aluminum, ceramics, copper, glass, magnesium, steel-bond solid propellants, cryogenic applications, insulation

FIGURE 10
Some common adhesives

297

title script, "Polymeric Materials" and three columns: polymer sample, name of polymer (trade names are OK such as Plexiglas™, Styrofoam™ or Superglue™ but also give the generic name such as acrylic, foamed polystyrene, and cyanoacrylate). In the third column give the favorable properties of the polymer.

- Layout the samples and labels on the posterboard for balance.
- Next (the hard part), determine means to attach the sample to the posterboard keeping in mind that not all polymers will form a bond with all adhesives, also first apply protective coating and adhesives to an adherent and allow to cure before mounting.

With an entire class working in teams of two or three to finish this construction project, the class should come up with a wide array of polymeric materials. Each team should tell the class their experiences with sample gathering, research, and testing on the sample polymers.

Summary

Polymeric materials are one of the main family groups of the family of materials. Polymers include both natural synthetic polymers with organic and hydrocarbons being the emphasis in this family group. Subgroups of engineering polymers include plastics, elastomers, wood, protective coatings, adhesives, lubricants, oils and a variety of fluids. Many subgroups exist within the main polymer subgroups. For example plastic may be classified in several ways such as engineering, general purpose, and cellular also as thermoplastic plastic and thermosetting plastic while wood can be divided into hardwood and softwood.

Because of the ability of materials scientists to provide unending polymer structures and since materials engineers can design and produce a wide range of fiber orientations while also creating polymer-based composite materials, polymers can truly be labeled "superstuff" (along with other non-polymeric engineering materials such as high temperature superconductors, semiconductors and diamond-film products).

These new polymeric materials include some wonder plastics which will join with other new technology and materials for a variety of innovative products. However, for these innovations to come about, we must have a cadre of properly educated people in a number of technical specialties plus a well educated citizenry as both wise consumers and intelligent voters to help usher in the 21st Century.

The members of the technological team are needed to produce the products and systems. The wise consumers are needed to demand high quality products. The intelligent voters are needed to insure that proper legislation is written to provide for a safe environment in which technology works for the betterment of society. How are you going to contribute to the future?

Possible Student Outcomes

- Recall the subgroups within the polymer group of the family of materials and the further breakdown of the polymer subgroups.
- Make comparisons between natural and synthetic polymers in terms of advantages offered by raw materials, processing, properties and applications.
- Explain some of the impacts that developments in polymeric materials may have on society.
- Defend a rationale for studying math, science and technology in preparing for a career, to be a wise consumer and intelligent citizen in the 21st Century.

Student Quiz

1. What are the main subgroups of polymeric material?
plastic, elastomers (rubber), adhesives, protective coating, and wood
2. Why are there so many polymers available?
Polymers can be synthesized from a wide range of raw materials
3. What is necessary to occur for adhesives to properly cover the adherent or substrate?
Must have good wetting of the adhesive on the surface of the adherent or substrate
4. In terms of raw materials resource what advantage do trees offer over natural gas, mineral oil, and metal ores?
Trees are renewable resources: they can be replanted for a relatively short growing period to make more wood and other forest products. Also, trees are relatively easy to process into wood.
5. Name some social/cultural impacts of polymeric materials.
Many innovations are emerging which can offer improvement of life but could also cause harm to people and the environment.

Acknowledgements

Figure 1 supplied by Dr. Wilfred A. Cote, SUNY College of Environmental Science and Forestry.

Figure 2, 3, 7—10 from *Engineering Materials Technology* (1985) by James A. Jacobs & Thomas F. Kilduff Reprinted by permission Prentice-Hall, Inc. Englewood Cliffs, NJ.

Figure 4 supplied by Firestone.

Figure 5 supplied by Forest Products Laboratory, Forest Service, USDA.

References

Jacobs, J.A. & Kilduff, T.F. (1985). *Engineering Materials Technology*. New York: Prentice-Hall.

Rogers, M. & Drew, L (1987, May 25). "The Age of Superstuff", *Newsweek*, pp. 73-74.

U.S. Forest Service. (1963, October). *Inside Wood—A Short Trip into the Interior for the Layman* FPL-014. Washington, DC: GPO.

Resources in Technology

Manufacturing In Space
(It's getting off the ground!)

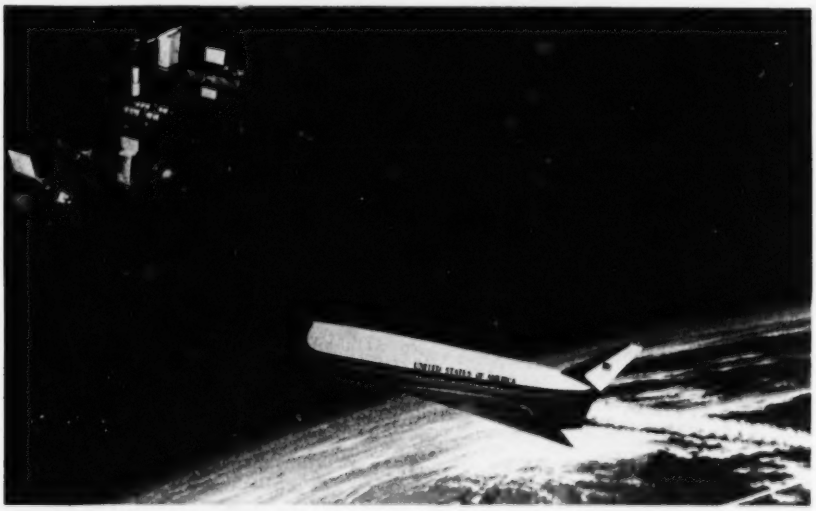


FIGURE 1
This artist's concept of a futuristic space craft could transport work crews from Earth bases to manufacturing facilities located in space.

Manufacturing in space may soon become a practical reality. Numerous experiments and projects by our Apollo astronauts have consistently demonstrated the possibility of such undertakings on both small and large scales. At the outset of any consideration regarding the feasibility of manufacturing operations in space, several very obvious questions immediately arise.

Why do it at all? What are its advantages and, conversely, its disadvantages? Do the advantages outweigh the disadvantages sufficiently to justify the costs which will necessarily be involved? What products might be manufactured more efficiently in space environments? What physical properties and forces might be involved which must be dealt with in order to ensure success?

These are just a very few of the countless questions which scientists and engineers must address prior to actually implementing full-scale "made in space" operations.

Much of the initial investigative work has already been done. As mentioned earlier, astronauts have already demonstrated the practicality and desirability of manufacturing products in space. For example, some products currently manufactured on the ground could be made to much more exacting specifications under the weightless conditions of in space. This includes items like some types of optical glass products, pharmaceuticals, and various alloys.

Numerous problems and/or concerns are immediately obvious. These include the difficulties of transporting large quantities of raw materials to space-based facilities and returning finished products to earth. But researchers working with the technology are confident that these (and others not cited) can be overcome.

Other considerations include the discovery of possible extraterrestrial sources (i.e., from places other than Earth) for the raw materials required for the products to be made, the use of cybernetics and/or humans, and the actual locations of manufacturing operations in space.

During the 1976 Summer Study at the NASA Ames Research Center at Moffitt Field, Calif, experts gathered to exchange ideas and to determine just what types of space manufacturing operations would be most beneficial and cost-effective. The results of that study may serve to give us some indication of the direction space manufacturing may take in the future and to illustrate some of its great potential. (Figure 1)

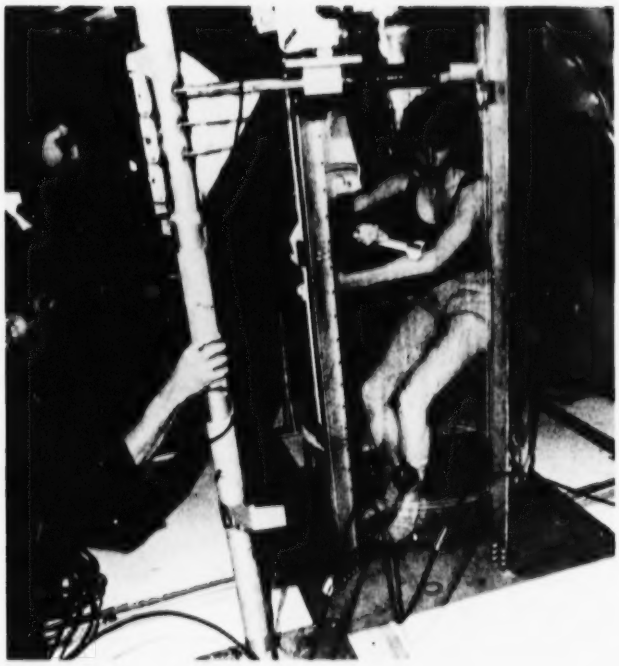


FIGURE 2
A test subject showers in a Plexiglas prototype of a space station shower. The unit is installed in a KC-135 aircraft which can help to simulate the weightless conditions of space.

Contemporary Analysis

Many early space experiments were conducted on Skylab 1, our experimental space station launched in 1973. In 1979—mainly due to the result of solar storms—it reentered the Earth's atmosphere and disintegrated.

The present centerpiece for space research and manufacturing operations is the planned Space Station. Assembly—in orbit— is now scheduled to be begin in 1993. By the following year, plans are that humans will be permanently on board, and full operations are scheduled to begin in the mid-1990's.

The Space Station will be a permanent, multipurpose facility in orbit which will serve as a laboratory to conduct basic research, an observatory to look down toward Earth or out into the heavens, a garage for servicing and repairing other spacecraft or satellites, a stopping point for spacecraft on their way to further points, and as a manufacturing facility. All in all, a very ambitious agenda has been chosen for our new Space Station.

The manufacturing facet of its operation will produce exotic metal alloys, super-pure pharmaceuticals, and perfect crystals.

The Space Station will also serve as a construction platform for materials or projects which are too large to fit in the cargo bays of spacecraft. It will also be a storage area for spare parts and even entire satellites. The operations and experiments performed relative to all areas of interest, including manufacturing, will help to perfect techniques and processes for future space operations.

Whether in space or on Earth, certain elements must be present for manufacturing operations to be possible. Let's look at just four of these as they relate to manufacturing in space. The four which are of particular interest to us at this time are:

- Human resources (people)
- Energy
- Raw materials
- Products actually produced

Human Resources

The element of human resources includes the people who will actually perform or control/monitor manufacturing activities in space. Because natural space environments are not conducive to human existence, certain accommodations will have to be made if humans are to survive, particularly for long periods of time.

Some human experiences, which may be very common and accomplished without much thought here on Earth, may conceivably present real challenges in space and its zero-gravity environment. In many cases, artificial gravity may be induced by rotating the space environment or by some other means.

Another relatively simple problem is presented by a human's need for almost daily showers. Obviously with no real gravity, waste water will not just run down a drain. One possible solution is to pressurize the clean water (as it is on Earth) and to vacuum the wastewater away with a hose (Figure 2).

Other parts of any artificial space environment would necessarily include some more provisions for comfortable, but practical, human existence.

The crew quarters where workers would stay is an excellent example of this accommodation process. Such quarters would be very compact, without an inch of space wasted. Within this area we would reasonably expect to find some type of health maintenance facility with monitoring equipment, a kitchen and food storage and preparation area, and sleeping accommodations (Figure 3).

These are only a few of the provisions that would have to be made in the crew's living area. Some provisions would also have to be made within the area of actual manufacturing operations in order to create an environment that would support human life.

While people would need to be present at any space manufacturing facility (i.e., to make decisions, judgment calls, etc.), they would not necessarily perform the actual manufacturing operations or processes. These might be accomplished more efficiently, accurately, and faster using industrial robots (robotics) or cybernetics.

The environment where the manufacturing occurred would only have to be suitable for the process involved. Any human operator or monitor could function from an enclosed control booth area which provided the needed environment (Figure 4).

Energy

The sun is the present obvious choice for a virtually limitless, readily available supply of energy in the space within

FIGURE 5
This crystal of geranium selenide was grown under weightless conditions in an electric furnace on board Skylab 1. The results of the experiment demonstrated that crystals grown in a zero gravity situation demonstrate greater growth and better composite structure than those grown in ground-based facilities. The crystal shown is 20 millimeters long and is the largest crystal ever grown in space.

PRODUCT	MEDICAL *APPLICATION*	*NUMBER OF ANNUAL U. S. PATIENTS*
Antitrysin	Emphysema	100,000
Beta Cells	Diabetes	600,000
Erythropoietin	Anemia	1,600,000
Interferon	Viral Infection	<10,000,000
Unokinase	Blood Clots	1,000,000

CHART 1 A Sample of Pharmaceuticals Which May Be Manufactured in Space

our solar system. For years, satellites have used the sun for power and to recharge their batteries. It has long been known (and dreamed) that the sun could supply all the energy needs of the Earth. A large platform consisting of giant antennas and solar collectors could conceivably collect sufficient energy for entire countries, with enough left over to supply the requirements of several space manufacturing stations.

A major problem confronting proponents of the use of solar energy to solve the power needs of space manufacturing facilities facilities is the enormous cost involved in beginning such an effort. Additionally, although scientists and engineers have attempted to foresee every possible problem, new difficulties will surely arise since our expertise in the area is so limited. New unforseen problems will certainly result in higher costs.

In addition to solar energy, it is quite possible that some technological breakthrough will emerge which will permit us to use some other form of energy. If, for example, the problems involved with nuclear energy, especially fusion, could be overcome, it could easily be adapted for use in space. In such a scenario, manufacturers would again have an almost limitless supply of energy.

Raw Materials

In 1978, the National Aeronautics and Space Administration (NASA) originated its Materials Processing Space Division. Because of this and NASA's continuing efforts to interest our economy's private sector in operations using the space shuttle, many commercial firms are presently interested in getting involved in space manufacturing. Experiments performed during earlier space missions have provided encouraging data regarding the manufacture of some products in space. One very interesting fact uncovered by both manned and unmanned flights was the discovery of so many different, usable mineral resources in various locations. Many of these are just the types of materials which will be required for manufacturing in space.

On various Apollo missions it was discovered that the moon had supplies of aluminum, titanium, and iron. Further, and even more interesting, it was revealed that although the moon had no atmosphere as we know it, oxygen was found to be present in many ores. This oxygen, so essential to our environment, could be extracted to be used on the moon and in space station environments. It has been determined that the oxygen to be used in space can be more cost effectively extracted and processed on the moon than it can be brought from Earth. In addition to supplying oxygen for breathing needs, it might also be used as a fuel source in some cases.

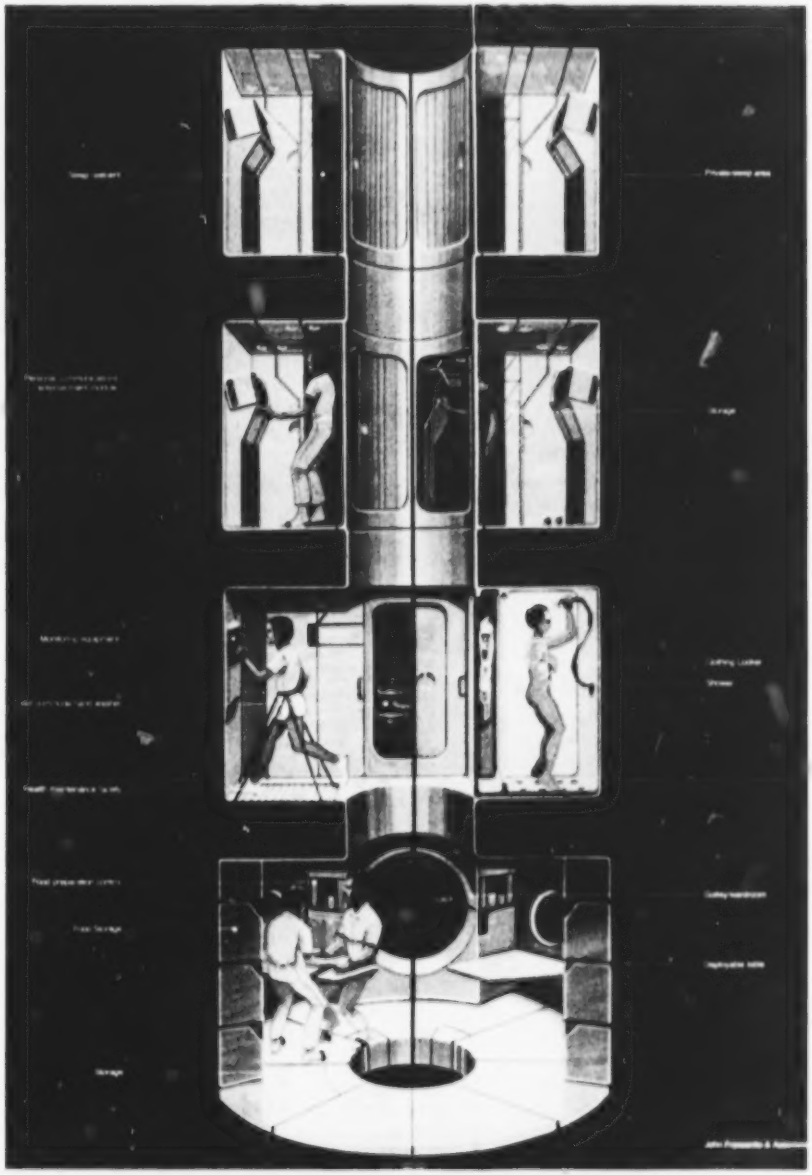
The planets and the thousands of asteroids in our solar system may also provide many of the raw materials needed for manufacturing in space. When examining meteorites found on Earth and using spectral analysis by telescope, many asteroids appear to have large supplies of valuable minerals—and hydrogen. The presence of hydrogen is extremely important since it may be combined with oxygen to form water for life processes and manufacturing operations.

Because of the varying level of gravity on the various planets, mining them for their resources seems impractical using existing technologies. The many asteroids present in our solar system, however, present a much more promising picture.

For example, once an asteroid was located that had ample supplies of a desired mineral resource, it could be nudged out of its orbit using rockets or some similar method and moved to a more suitable location for mining. This location would probably be in the vicinity of the manufacturing facility which would be using the materials extracted. While waiting for mining operations to begin, the asteroid could be placed in nearly the same orbit as the manufacturing/mining facility.

Solar energy could power the processing of the minerals or ores. The processed materials could then be used at that location or shipped to other space-based facilities for use. If the user was on Earth, the materials could be processed with vacuum bubbles inside for flotation purposes and sent to Earth for an ocean splashdown. The slag generated during materials processing could be used as a heat shield to prevent the materials from burning up as they entered the Earth's atmosphere.

The extraction of raw materials and their movements could be accomplished using the generally accepted methods of mining and proposed shuttling by space craft. A very different and



interesting method of accomplishing the same thing has been extensively investigated by Gerald K. O'Neill of Princeton University.

He envisions the extracted materials being "thrown" or "catapulted" into space using electromagnetic mass drivers. The feasibility of the concept becomes more evident when you remember that the moon's gravitational pull is only one-sixth that of Earth. Once the hurled material reached its destination in space, it would be "caught" in large funnel or cone-shaped devices called "mass catchers." The materials could then be placed in an orbit, waiting to be used.

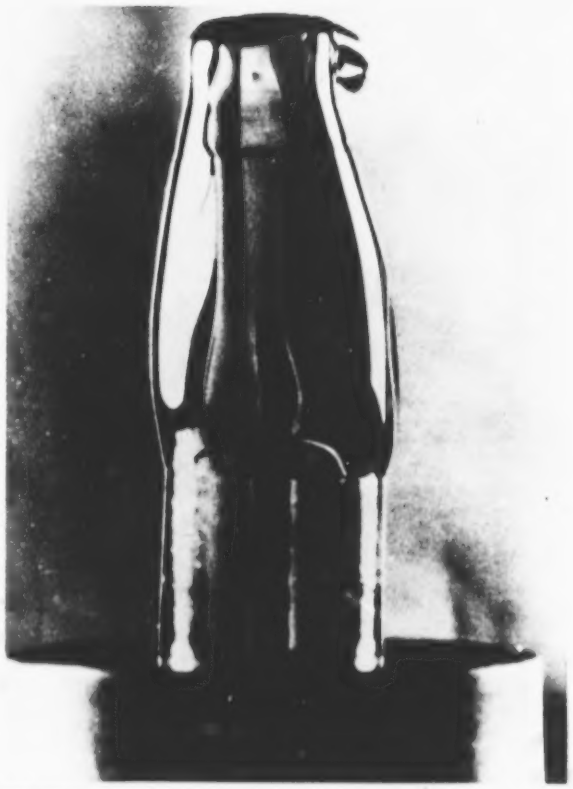
Products from Space

Initially, products manufactured in space would be used back on earth or in a very limited space environment. For example, in the field of pharmaceuticals, a large number of products may be better and more profitably manufactured in space and the conditions it imposes (Figure 5 & Chart 1). As the technology for space manufacturing improves, even more of this type of product may be produced

FIGURE 3
Within the crew's living quarters at a space manufacturing station, environmental controls and life support systems would be designed to provide personnel with a breathable atmosphere and a water supply for bathing, drinking, and for food preparation. The systems would also remove contaminants from the air and process biological wastes.

FIGURE 4
While the majority of space manufacturing operations could be accomplished using robotics, some human input would still be required. Humans would be able to monitor operations from control areas such as this one. The environmental control required would probably be considerably less than would be needed for the entire manufacturing area.

FIGURE 6
This photograph shows an ultra-pure semiconductor from space. It is made of indium antimonide and was formed on Skylab 1. The material was heated until molten and allowed to cool and solidify in a space environment. This semiconductor is extremely homogeneous, free of flaws, and smooth. It is not presently possible to produce similarly perfect single crystals on Earth.



in space. There are both advantages and disadvantages regarding manufacturing in space. Even at this early stage in the development of space manufacturing technology, the pros seem to outweigh the cons. In addition to those already mentioned, such as zero-gravity conditions, other positive aspects of manufacturing in space are already evident. Depending on the actual location of the manufacturing site, temperatures range from extremely hot to absolute zero (−273°C) conditions. Because of the isolated sites for manufacturing in space, potentially dangerous activities, such as DNA research, might also be wisely and more more safely conducted there.

Many other products will also benefit from being manufactured in space. Some of these are pure crystals (Figure 5), optical fibers, and semiconductors (Figure 6).

As transportation to and from space is presently so expensive, the first type of products to be manufactured will necessarily be small. This is so that after large quantities are produced they may be transported simultaneously. As the transportation costs decrease, somewhat larger products may be produced.

Once such manufacturing operations are in place and production methods, transportation, and other requirements are met, it is predicted that much larger operations will begin. It is also generally expected that they will be quite successful.

Very large quantities of ore will be processed and transformed into standard stocks and other special forms. The larger materials and other products produced may be used in space to build other space stations, manufacturing facilities, and space ships. Many awkward and very large manufacturing and/or construction operations, that require parts too large for transport from Earth, could be accomplished in space, taking advantage of the zero-gravity conditions found there.

COMPANIES	*PRODUCTS/PROCESSES*
Westinghouse	Glass for lasers and telescopes, and glass-forming alloys
Westech Systems Microgravity Associates Honeywell Corporation	Semiconductors and crystal
Aluminum Company of America International Nickel Company John Deere and Company Bethlehem Steel	Metals processing

CHART 2
Companies Presently Planning for Manufacturing in Space

In these conditions, space vessels could be launched in space from stations or platforms to transport materials to the various using locations. In so doing, the tremendous amounts of fuel usually consumed during a launch from Earth and its gravitational forces would not be required.

Many commercial companies are presently interested in manufacturing in space and are working with NASA to explore product possibilities and material properties in space. A list of just a few of the firms involved and the products they plan to produce is shown in Chart 2.

Social/Cultural Impacts

Extensive manufacturing in space efforts will become a reality in your lifetime. The products made there will not only be produced more economically, but will also be of a better quality than was previously possible. As the fledgling industry grows and begins to expand to whatever limits prove economically practical, the quality of life on Earth for all people should improve. New drugs, medicines, and other biological products will increase the number of years humans may expect to live. As a consequence of this, the number of years that they may be contributing members of society will also grow. The technology that will change our lives forever and ultimately carry us to the other planets and beyond will surely change the way we perceive things here on Earth.

When your grandparents were young, a computer would fill an entire room and take minutes to make relatively complex calculations. Today, a computer may be carried in your hand and perform extremely complex functions in just microseconds. In the same manner as our society's thinking was changed regarding computers, so too will its perceptions about space and the activities found there also change.

In addition to space travel, manufacturing facilities in orbit, and new living sites with manmade environments, a multiple of new discoveries awaits us in space. While it may seem to some to be only a science fiction writer's dream, other knowledgeable persons know that Humankind is about to embark on its grandest adventure of all. As it does, manufacturing in space will play a major role.

Construction Activity

Construct A Model Space Manufacturing Facility

Discussion—Working as a team, have class members discuss manufacturing in space and the various elements involved (i.e., people, materials, processing, equipment, storage, transport, etc.).

Design—Divide the class into groups or work as one group and design an "ideal" space manufacturing facility. Tell the students that the design must incorporate provisions for the elements identifed in the earlier discussion as well as any others which are selected as being necessary (i.e., life support systems, etc.). Cost need not be a factor during the design process.

Present Ideas—Bring the class back together and have each group present its ideas for the proposed facility using drawings, charts, and oral presentations. Have an open discussion regarding the pros and cons of the various features of each design.

Evaluate—Decide on the best and most appropriate features of each group's design. Using the features determined to be the best and which will make adequate provisions for the varied needs of the space manufacturing facility, incorporate them into the design for one three-dimensional model. More than one model design may be selected and built, depending on class size and the time allotted for the project.

Note—If time permits, seek information from outside sources such as NASA (address: NASA, Lyndon B. Johnson Space Center, Houston, TX 77058).

Math/Science/ Technology Interface

As humans begin to consider the extraction of materials from one site, such as the moon, and the transport of them to another, such as a space manufacturing facility, the interface of mathematics, science, and technology becomes increasingly important. Before payloads can be moved from one location to another, many scientific facts must be determined or calculated. Not the least among these are the various different gravitational forces which must be known and dealt with.

Sir Isaac Newton stated in his "law of universal gravitation" that every body in the universe attracts every other body with a force that is directly proportional to each of their masses and inversely proportional to the square of the distance between them. When we state this as an equation, we get:

$$\text{Gravitational Force} = F = G\,\frac{m_1\,m_2}{r^2}$$

In the equation, m_1 and m_2 are the masses of any two bodies. The distance between them is r and G is a constant whose values in SI units are:

$$G = 6.67 \times 10^{-11}\,\frac{N - m_2}{kg^2}$$

In order to find the gravitational force the Earth exerts on the moon, use the following data:

Earth's mass = 5.98×10^{24} kg
Moon's mass = 7.36×10^{22} kg
Average radius of moon's orbit = 3.84×10^{8}m

Using the formulas given, we have:

$$F = G\,\frac{m_1\,m_2}{r^2}$$

$$= 6.67 \times 10^{-11}\,\frac{N - m^2}{kg_2} \times \frac{5.98 \times 10^{24}kg \times 7.36 \times 10^{22}kg}{(3.84 \times 10^{8}m)^2}$$

$$= 1.99 \times 10^{20}\,N$$

Gravitational force is one of the four existing fundamental forces. These are so called because they cannot be explained in terms of any other force. The other three fundamental forces are electromagnetic, weak nuclear, and

strong nuclear. Gravitational forces act between all masses and are important in determining the structures of planets and other bodies in space. They are also an important aspect of space travel and any manufacturing operations which may occur there.

Although much of this information seems to come straight out of a science fiction novel, many experts believe it presents a true representative picture of the future for manufacturing in space. While the launching and use of satellites is fairly common practice today, manufacturing in space is still occurring on only a very small scale.

Late in 1987 competitive contracts for hardware development were awarded for the building and assembly in space of a space station which should be manned by the mid-1990's. It is to be designed so that planned additions may regularly be made to it while it is in orbit (Figures 7, 8, 9 and 10).

Manufacturing in space is literally "still on the drawing boards." Some major technological problems still remain to be solved before full implementation of any operations can actually begin. It is predicted, however, that by the year 2000 several industrial sites will be in use in space. At that time we can look forward to products which are truly "Made In Space."

FIGURE 7
This computer generated drawing shows an early stage (Phase 1) in the development of the permanently manned space station. It features a horizontal truss to which laboratory and habitation modules, and solar panels are attached.

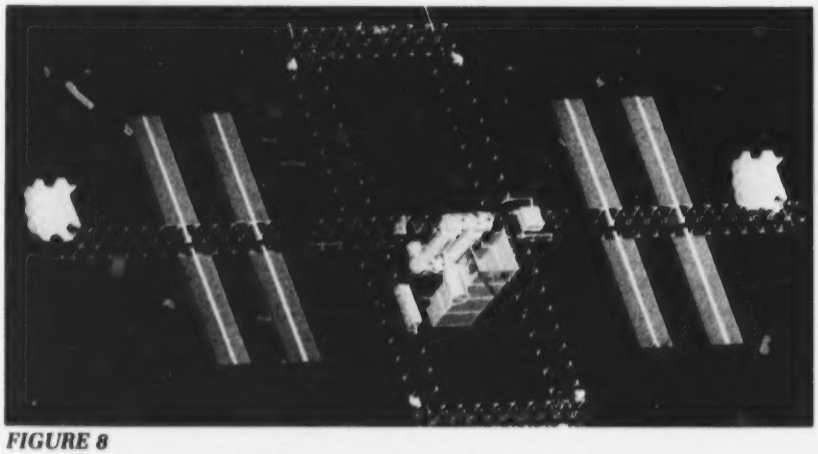


FIGURE 8
This computer generated drawing shows a later stage (Phase 2) in the development of the same station. It now includes upper and lower keels for attaching external payloads, a 50 kilowatt solar dynamic system mounted on the ends of the transverse beam, and a servicing bay.

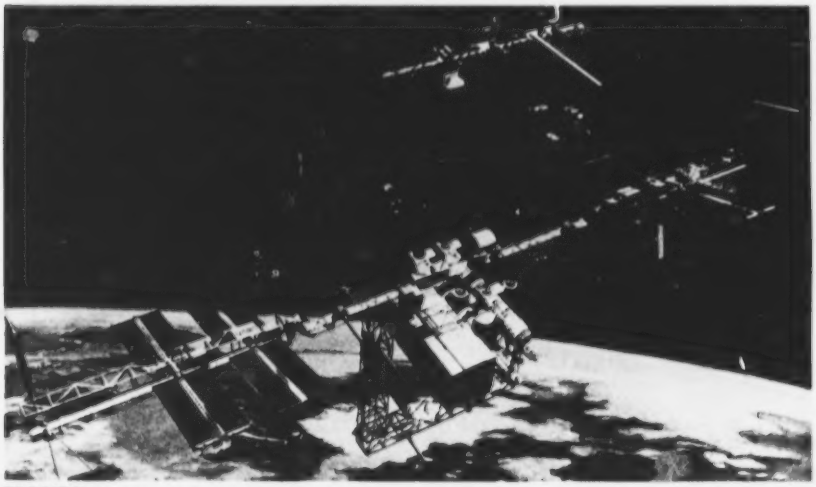


FIGURE 9
This is an artist's concept of a completed space station.

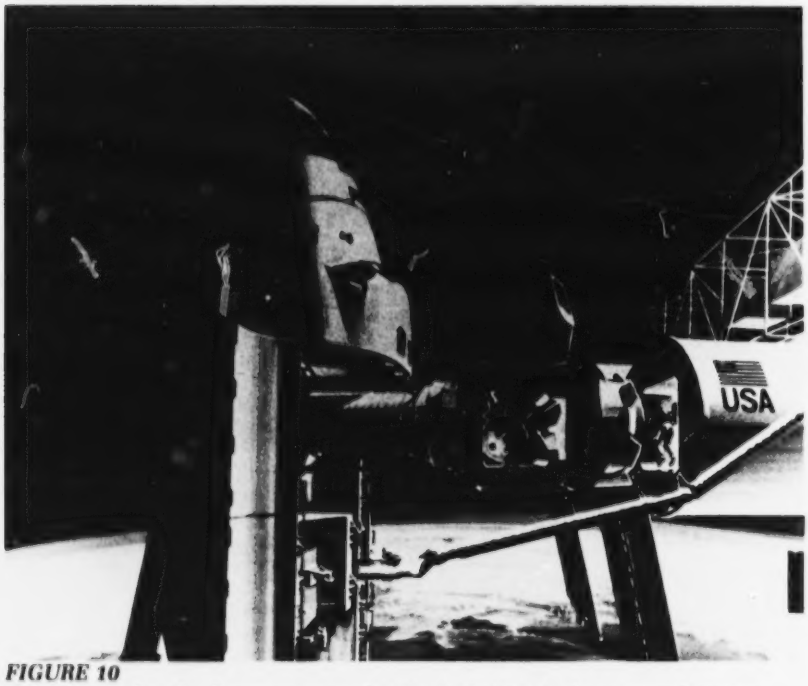


FIGURE 10
This figure clearly shows a space shuttle docked with the manned station. Also readily seen in the drawing is the Canadian-built remote manipulator arm which will assist in the assembly and maintenance of the space station. One set of photovoltaic solar arrays can also be seen.

Student Quiz

1. Name three products presently manufactured on Earth which may be more effectively produced in a space-based facility.
2. How will the space station presently proposed by NASA be used? What benefits do you think might accrue from its use?
3. Since it will be possible to do most operations associated with manufacturing in space using robotics or other advanced technologies, do you think it will still be necessary to have some humans present? Why or why not?
4. What types of manufacturing operations might be better suited to the use of robotics or cybernetics than to the use of human resources? Why?
5. List and explain some of the advantages of using solar energy for manufacturing in space. Are there any disadvantages that you can think of?
6. Discuss the possible effects of NASA's involving private industry in the development of manufacturing in space.
7. Explain why it might be more beneficial to use materials extracted from the moon or the asteroids for space manufacturing rather than using materials from Earth.
8. List some of the elements which are available using lunar resources. Use other sources such as encyclopedias, magazines, etc.
9. Explain why some products manufactured in space, such as pharmaceuticals, might improve the quality of life on Earth.
10. Future major construction and manufacturing projects in space may be used to aid in explorations of deeper space. Discuss the possibilities. Try to think of technologies which would have to be developed.

Possible Student Outcomes

- Describe the necessary major components of a manufacturing facility in space.
- List several products which may be manufactured in space.
- Explain why it may be cost-effective to use nonterrestrial materials for manufacturing in space.
- State several advantages of manufacturing in space.

References

DeOld, A.R. (1986). *Transportation: the technology of moving people and products.* Worcester, MA: Davis.

Goldman, N.C. (1985). *Space commerce: free enterprise on the high frontier.* Cambridge, MA: Ballinger.

American Institute of Aeronautics and Astronautics. (1976). *Space manufacturing/space colonies.* Proceedings from the Princeton Conference. New York: Author. American Institute of Aeronautics and Astronautics. (1977). Space manufacturing from nonterrestrial materials. *Progress in Astronautics and Aeronautics, 57.* New York: American Institute of Aeronautics and Astronautics.

Space Station. (1986, December). Washington, DC: National Aeronautics and Space Administration.

Acknowledgement

All photographs and drawings were supplied by Mike Gentry, NASA, Lyndon B. Johnson Space Center, Houston, Tex. His cooperation is gratefully acknowledged.

Resources in Technology

Metallic Materials

FIGURE 1
The Spaceship Earth exhibition and Walt Disney World Mark IV Monorail system at Epcot Center are examples of the application of metallic materials to engineering.

Metallurgy is a science devoted to study of metallic materials which includes metal and their alloys. Metallurgy is the oldest and most established branch of materials science and engineering (MSE). MSE represents a relatively new discipline dealing with all of the materials used by society and the study of materials structures, properties, processes and applications. MSE owes much to the metallurgists who unlocked the mysteries of metallic materials to produce tens of thousands of metals and alloys (metal combined with other elements) for service to humanity.

While materials scientists produce new materials such as superconductors, advanced composites, miracle polymers, and high tech ceramics on nearly a daily basis, metals continue to stand as the dominant material for many engineering in transportation, communication, and production. This dominance, while being aggressively challenged by polymers, ceramics, and composites, attest to metals' ability to withstand severe stresses whether they be mechanical, thermal, or chemical. Additionally, many engineers are familiar with metals, especially steel, and feel comfortable designing, processing, testing, and maintaining it.

This module will expose you to the basic concepts of metallic materials and, hopefully, spark an interest that will cause you to study more about metals.

Social-Cultural Impacts

Engineering materials technology covers the fields of applied science related to the science of materials, materials processing, and the many engineering specialties dealing with materials, such as research, development, design, manufacturing, construction, and maintenance (Jacobs & Kilduff, p. 14). Many people work in engineering materials technology and the entire world depends upon their work. Fine rewards accrue to those on the engineering team (engineers, technicians, craftspeople, and scientists) who contribute to humanity through engineering materials, but there are grave circumstances for those who become negligent in doing their work.

On July 17, 1981, 114 people were killed and 200 more injured when two 70,000 pound walkways collapsed in the Kansas City Hyatt Regency Hotel. The failure of the walkways were blamed on the engineering firm that designed the facility and had responsibility for its construction. The collapse involved problems with a metal and concrete connection system. After a through investigation, the state's circuit court found the company president, vice-president and the chief engineer on the project were found guilty of gross negligence because they failed to perform the necessary evaluation of the structure to insure adequate safety. The Missouri licensing board voted to revoke their licenses. As in this case, the civil liability of this type of human error often results in action that brings ruin to those involved.

In 1986 the worst U.S. nuclear energy accident to date occurred at the Surry (Va.) Nuclear Power Plant causing the death of six workers and injury of two others. The workers were scalded by superheated steam released when a large carbon steel pipe burst.

The pipe broke as a result of erosion/corrosion which wore the pipe too thin to hold the pressurized steam. In this case investigators did not find any individuals negligent.

But the accident could have been prevented had the proper analysis been made of the stresses and environmental conditions acting on these steel pipes.

These cases and many more point to the serious responsibilities entrusted to the members of the engineering team.

On the other hand we see an infinite number of examples of valuable work which provides a better way of life for humanity coming from people in engineering who apply principle of metallurgy, strength of materials, and the full spectrum of engineering technology.

And we, as citizens in a technological society, all require some basic knowledge of metallic materials to be intelligent consumers and responsible citizens.

Nature and Properties of Metallic Materials

Metals are selected for a particular engineering application based on their properties. A material's properties are a result of the nature of the internal structure of the material.

To gain a perspective of how much metal is used, carefully examine Figure 1 and make a list of as many possible applications of metals as you think are represented in this photo.

In the background of this photo of Disney World's Epcot Center is Spaceship Earth. Countless metals and alloys are involved in this geodesic sphere which seems to float off the ground. The outer skin of anodized aluminum offers but only a hint to the many metals involved which range from 1,750 tons of steel for structural purposes, to the many metals that make up the ride and planetarium attraction including copper electrical wiring, brass valves, tungsten light filaments and brass bulb bases, and powered metal or cast iron alloy magnets for loud speakers and electric motors.

In the foreground the monorail train rests on a concrete beamway track with reinforcing steel bars, the sidewalk uses reinforcing steel wire. The train runs on electricity that is picked up from the metal power rail on the concrete beamway. Numerous metals go into the train for door handles, screws and bolts, structural frames, and motors.

We could go on for pages analyzing this one scene to determine the use of metals. You should pause on occasions and ponder over a given setting such as we have done with this Epcot attraction and think about uses of metals based on their nature and properties.

Metals in a strict definition refer to the elements in the Periodic Table of Elements such as iron (Fe), aluminum (Al), gold (Au), tungsten (W), and tin (Sn). Metal elements comprise about three-quarterst of the known elements.

"Metallics" is the term which includes both the pure elements and their alloys such as steel (iron and carbon—FeC), brass (copper and zinc—CuZN) or sterling silver (silver and copper—AgCu). It is common practice to use the terms metals and metallic materials interchangeably.

Metals Defined

A number of definitions may be used to define metals. The chemist considers their atomic structure—most metals have less than four valance electrons (electrons in outer orbits of the atom), while nonmetals elements such as carbon (C) or chloride (Cl) have four or more valance electrons. An engineer tends to define metals with regard to their properties—hardness, toughness, malleability, electrical and thermal conductivity, and corrosion resistance. Metals normally have a microstructure of millions and millions of crystals known as grains which can be observed through a metallurgical microscope (Figures 2 and 3).

Phases in Metals

Phases are homogeneous parts of a material that differ from other parts due to differences in microstructure, composition or both. Changes in temperature and pressure will cause some metals and nonmetals to change their crystal structure and phases. Carbon, a nonmetal, can exist in one phase which is

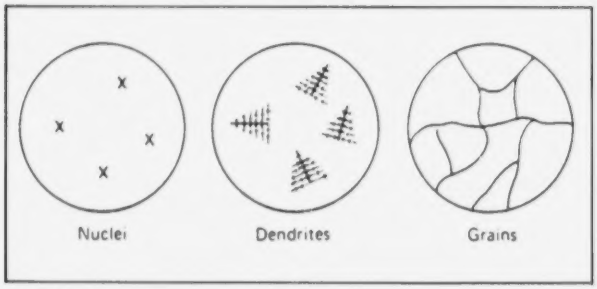


FIGURE 2
As metal cools from a liquid it begins to form nuclei that grow to dendrites than to grains.

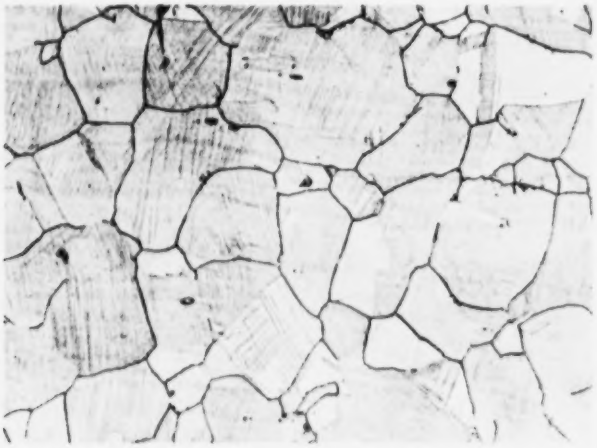


FIGURE 3
Grains of manganese steel at about 100 magnification show grains.

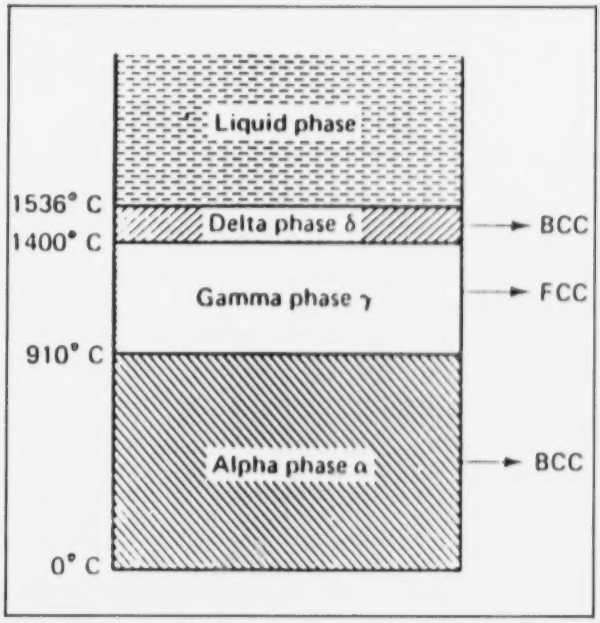


FIGURE 4
Phases of iron in solid state crystal space lattices of BCC, FCC, BCC.

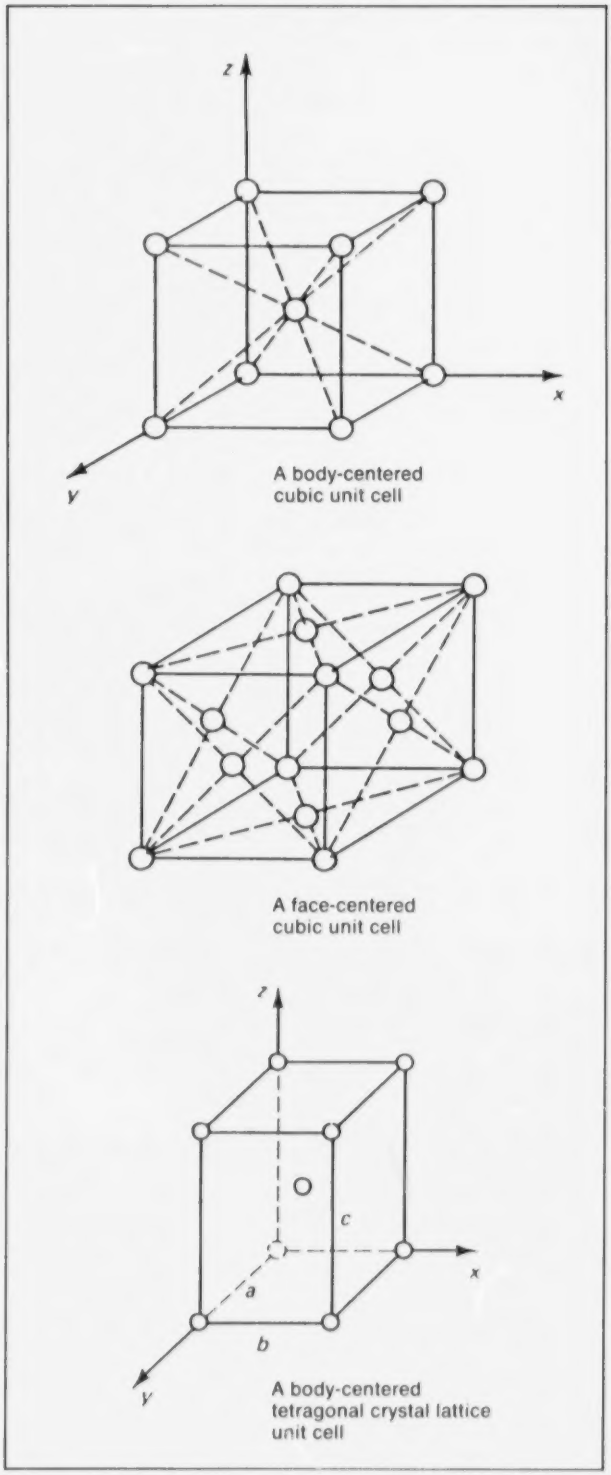


FIGURE 5
Iron changes from a BCC structure at room temperature to FCC at 910°C. With carbon alloyed in iron to form steel, rapid cooling will trap the carbon and form a BCT space lattice which makes a harder steel than would form if slow cooling was permitted.

soft such as graphite, but high pressure can turn carbon into hard diamond another phase.

The ability of iron to exist in several phases allows us to make thousands of alloy steels and to heat treat these alloys to produce a wide range hardness and toughness. Figure 4 shows a phase diagram of iron while Figure 5 depicts the crystals space lattices of two phases of iron:

- Body-centered cubic (BCC)
- Face-centered cubic (FCC)

These are phase changes that occur while the metal is still in its solid state. When iron is heated to 910°C it changes to an FCC structure. While in this phase, which is still a solid, iron can absorb more carbon atoms than when in the BCC space lattice structure.

If the solid alloy (FeC) is cooled at a rapid rate, the carbon is trapped and will produce a distorted crystal structure which is no longer cubic, rather a body centered tetragonal (BCT) as seen in Figure 5.

Had the alloy been allowed to cool slowly, then most of the carbon would precipitate out of the solid solution so the crystal structure would be mostly BCC again. The BCT crystal structure gives the steel a hard and brittle property. This material can then be reheated to the proper temperature and held there for a predetermined time to make the alloy slightly softer but at the same time increasing toughness.

Figure 6 is a simplified phase diagram of iron and carbon. On the x-axis you see the percentage of carbon added to the iron. Up the y-axis you observe the increase in temperature. The A3 line reveals that as carbon is increased in the alloy the temperature required to reach a FCC (gamma iron) crystal structure goes lower. This continues until about 0.80% carbon is reached, then the temperature for reaching FCC goes up until it hits 2% carbon and then levels off. The alloy above 2% carbon is called cast iron; from between 2% to 0.008% carbon we call the alloy steel; and from 0.008% to 0% carbon is know as wrought iron.

Phase diagrams are known as the heat treaters road map. Heat treatment becomes very involved and allows many variations within an alloy in terms of the metals hardness, toughness, and electrical properties. There are many career options related to metallurgy that range from technician positions as heat treaters to positions as materials engineers to metallurgists and materials scientists (Figure 7).

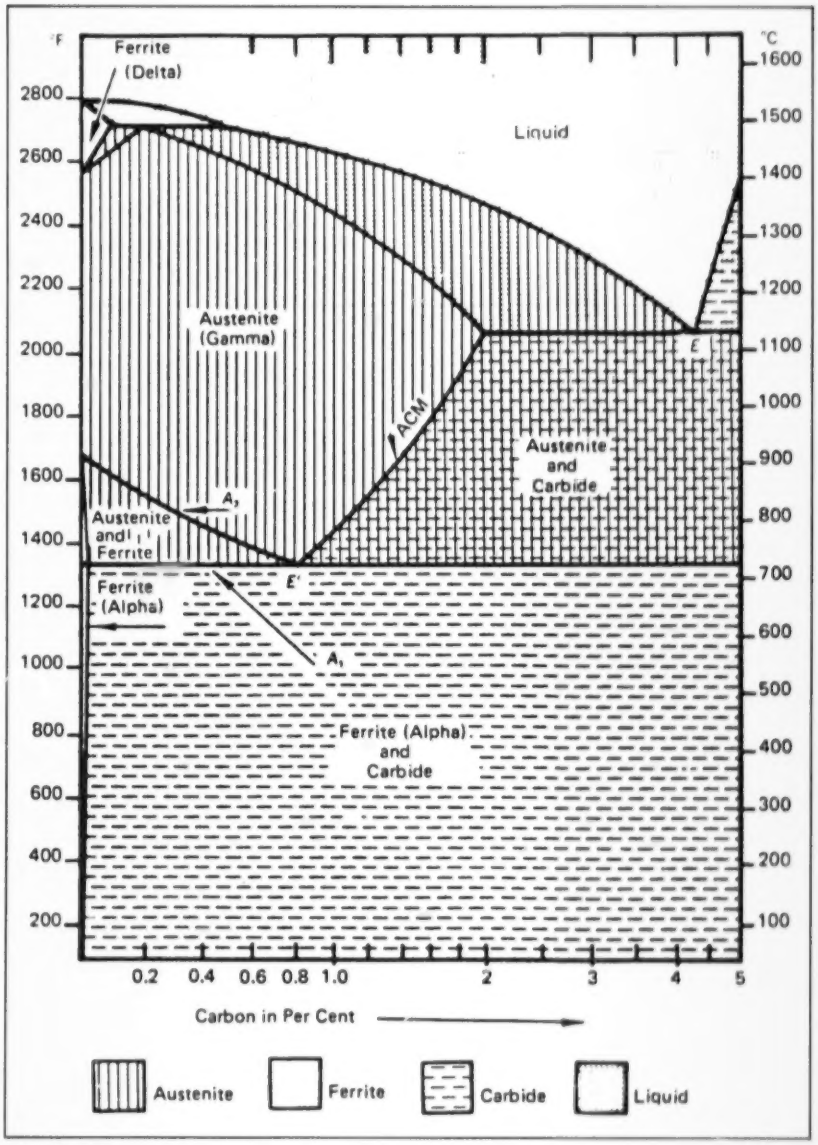


FIGURE 6
Iron-Carbon Equilibrium Phase Diagram shows the effect of adding carbon to iron and temperature on the phases changes of these iron alloys. The equilibrium diagram results from slow cooling.

Classification and Application

Table 1 shows how metallic materials comprise one of the main groups of the Family of Materials. We have the metallic group divided into the subgroups of ferrous, nonferrous, and powered metal with examples given for each subgroup.

Ferrous Metals

This group includes iron and alloys of at least 50% iron such as cast iron, mild steel, tool steel, and stainless steel. Ferrous is the Latin word for iron and the symbol for iron is Fe.

Steel is by far the most widely used alloy and is all around us. Sheet steel is used for auto and truck bodies, office furniture, appliances, "tin" cans, and thousands of other uses. Heavier steel such as plate, structural "T" and "I" beams serve as frame for buildings, ships, bridges, and automotive chassis.

Steel is facing aggressive competition from plastic and aluminum due to their

FIGURE 7
The National Bureau of Standards Metallurgy Division develops phases diagrams, the all-important road maps for new alloy development. Physicist Joanne Murray analyzes data used to create these phase diagrams.

FAMILY OF MATERIALS		
Group	Subgroup	Examples
Metallics (metals and alloys)	Ferrous	Iron
		Steel
		Cast iron
		Steel alloys
	Nonferrous	Aluminum
		Tin
		Zinc
		Magnesium
		Copper
		Gold
		Nonferrous alloys
	Powdered metal	Sintered steel
		Sintered brass

TABLE 1
Metallic group from the Family of Materials.

lighter weight, ease of fabrication, and corrosion resistance to name but a few advantages. However, much of industry is already set up to deal with steel. This production system involves all stages from extracting raw materials and recycling scrap to production of stock material to fabrication of parts. Because all these systems are in place, steel is very cost competitive which often is the overriding factor in material selection. Plus the steel industry constantly strives to innovate.

One such development, the PASER, is depicted in Figure 8 cutting through steel plate. In this water jet system, water mixed with abrasive particles is driven at pressures up to 55,000 psi to cut metal as thick as 6". In contrast to flame cutting of metal, the water jet system creates no heat thereby eliminating metal distortion while leaving an exceptional finished edge.

Nonferrous Metals

Metal elements other than iron and alloys with less than 50% iron are in this group. Even though more steel is used, there are many more nonferrous metals available but there are many reasons they are not used in large quantities. One reason certain nonferrous metals are not used is the difficulty and expense of extracting them from their ore. Also some nonferrous metals are not as abundant in the earth's crust such as chromium and platinum.

Aluminum (Al) is the most abundant of the metal elements with more than 15% of the earth's crust containing aluminum locked up in rock and soil often as aluminum oxide (Al0). Unfortunately, it requires complex electrochemical processes to separate the aluminum from its ore.

The expense of winning aluminum from the ore justifies the necessary efforts to recycle aluminum products since about 75% of the energy is saved when aluminum is recycled compared to when the virgin aluminum is obtained from ore. An efficient process of refining aluminum was not developed until 1886.

Aluminum has many favorable properties including ease of processing, excellent thermal conductivity, good strength, corrosion resistance, and light weight (only one-third of steel).

As with steel there are many alloys of aluminum. Generally, aluminum in continuous service conditions does not withstand increased temperatures (above 300°F or 150°C) as compared to other metals such as steel and titanium of higher weight.

Exotic alloys of aluminum with copper, lithium, magnesium, oxygen and zirconium (AlCuLiMgOZr) do provide good strength and low weight while being able to withstand temperatures in the 300°F (150°C) range for prolonged periods of time. These newer alloys can serve as structural components in high performance aircraft where the heavier titanium alloys were once used.

Zinc (Zn) is a nonferrous metal that has a metallurgical history dating back to 2000 BC in India where a method of refining zinc from ore was discovered. Zinc, a white metal, is easy to cast with a melting temperature of only 420°F (215°C).

Zinc formerly was die cast into many parts ranging from chrome plated ornamentation on automobiles (bumpers, door handles and trim) to jewelry, portable power tools, and small appliances. Recently, plastic and aluminum have replaced zinc for most of those applications. Galvanized sheet metal is steel dipped in zinc and finds such applica-

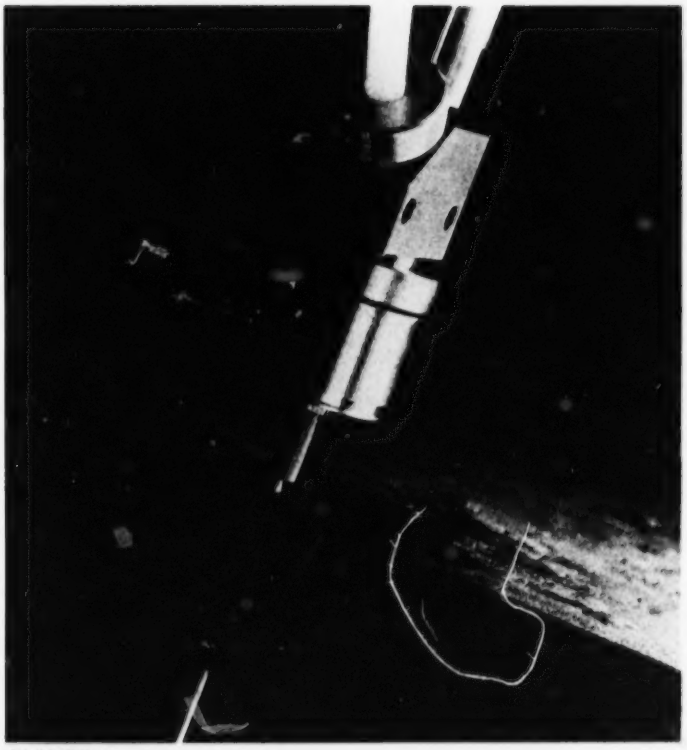


FIGURE 8
Water jet cutting is a new technology that provides distortion-free metal cutting.

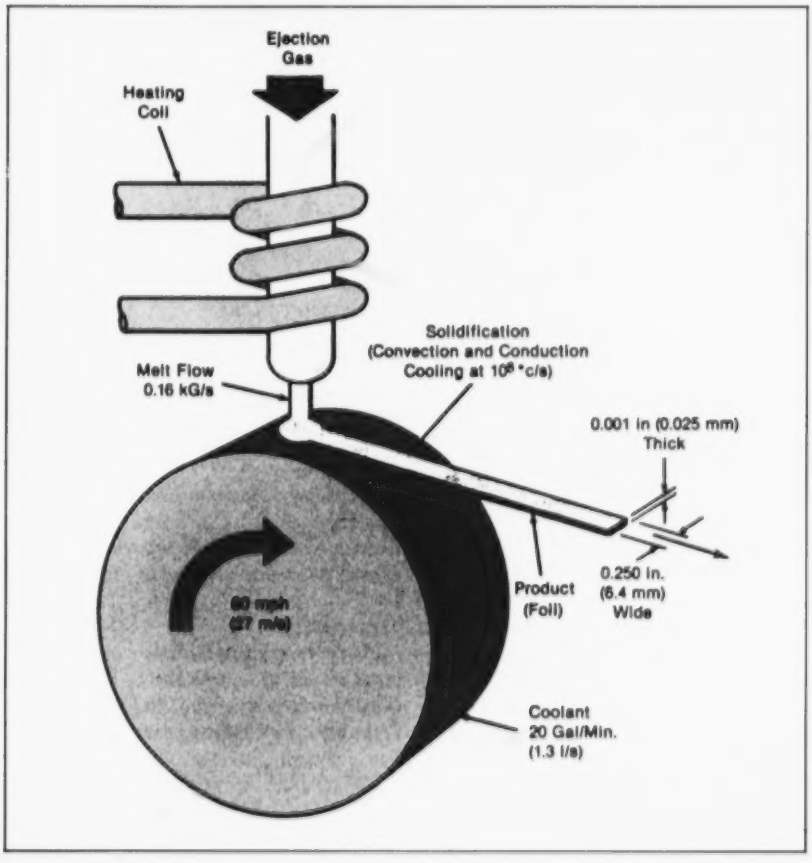

Ejection Gas
Heating Coil
Solidification (Convection and Conduction Cooling at 10^6 °c/s)
Melt Flow 0.16 kG/s
0.001 in (0.025 mm) Thick
Product (Foil)
0.250 in. (6.4 mm) Wide
60 mph (27 m/s)
Coolant 20 Gal/Min. (1.3 l/s)

FIGURE 9
Rapid-solidification of metal occurs as molten alloy strikes a liquid-cooled rotating drum.

tions such as heating ducts and other uses where rust resistance is desired. It is possible to see grain patterns on galvanized steel with the unaided eye.

Copper (Cu) finds many applications as an alloying element, as a base metal for adding other elements, and as a pure metal. Copper-based alloys include brass (copper and zinc—CuZn), bronze (copper and tin—CuZn), cupronickel (copper and nickel—CuNi) and nickel silver (CuNiZn).

As with aluminum, copper develops a protective outer oxide coating for rust resistance. Copper of the highest purity (+99%) provides good electrical conductivity, but glass optical fibers are gradually replacing copper in communications systems.

There are countless other nonferrous metals and alloys which you should find interesting to study about.

Newer processes being developed for the metals industry aim to keep metal competitive with plastics, composites, and ceramics. One such processes that has seen a lot of R&D by the National Bureau of Standards and NASA is rapid solidification. As shown in Figure 9, rapid solidification involves directing a stream of molten metal onto a cooling wheel rotating at 60 miles per hour for 27 meters per second feed rate to rapidly cool the liquid metal to a solid metal ribbon.

By solidifying the metal at a quenching rate of 1,000,000°C per second, grain sizes are reduced, alloying elements disperse more completely in the base metal, and unique mechanical and physical properties develop that serve in high temperature and electrical applications.

Alloys with copper and aluminum bases are getting much of the attention of rapid solidification. Tailored alloy combinations such as aluminum-lithium-beryllium and copper-chromium cannot be achieved by ingot casting because the alloys segregate upon cooling.

Rapid solidification is also achieved with powdered metal. In the atomization process small particles are produced as streams of alloyed metals are blasted with air.

Powdered Metals

The PM processes involves creating small particles of metal through a vari-

ety of techniques including crushing, atomization, and shotting (dropping metal through a screen down a high tower into a water tank at the bottom). These particles can then be blended with ceramic particles, lubricates or other metals.

Next, the parts are compacted in large presses. The degree of pressure from the press and size of the particles determines how dense the PM part will be. Sometimes it is desirable to have porosity in the part if it will serve as a filter perhaps to be used as a inline gasoline filter or impregnated with grease and used for self-lubricating bearings. The very dense PM parts might be used as cutting tool inserts of cermets (ceramic metals) such as titanium carbide (TiC) and titanium nitride (TiN).

Next, the particles form bonds in the sintering step during which the part is heated to a temperature which cause adhesion of the particles. Sintering does not normally melt the metals, but may melt some of the lower melting point particles.

Sintered metal is the term often applied to PM parts. These parts offer many advantages over machined and cast parts. Some benefits are little or no scrap, the ability to join parts of materials with large differences in melting points, and the ability to produce large numbers of parts with very close tolerances and excellent surface finishes.

Superconductors are materials which offer no resistance to flow of current through them. In 1911, H.K. Onnes demonstrated that metals could be made to pass electricity without any resistance; but the metal—in the first test mercury—had to be cooled to near absolute zero, 0° kelvin or −460°F.

In 1987 scientists made major breakthroughs by demonstrating superconductors that could operate at temperatures relatively hot −54°F (−47.8°C). The race is now on to develop superconductors approaching room temperatures that can be produced commercially.

Considerable worldwide R&D efforts on these newly emerging materials race on because of the promise offered by superconductors in such areas as high-speed computers, medical devices, high-speed levitating trains, and more efficient electrical power transmission.

A variety of materials are being explored to generate the proper combinations of metal oxides that yield a space lattice which allows electrons to pass through the material without resistance.

Construction Activity

Oberserving metallic materials in products can help you gain a better knowledge of how the material's properties relates to suitable uses. Gather some objects such as nails, screws, and clocks, radios, toys, and similar ites, If you can locate an old radio with a speaker, the speaker will have a very powerful magnet in it.

How do you separate ferrous from nonferrous metals? Remember that ferrous is Latin for iron. Iron is a magnetic material and most nonferrous metals that you find in common products are nonmagnetic. Those objects that attach themselves to the magnet are probably iron or steel; some stainless steels are nonmagnetic. Those metals with brownish yellow or yellow color will be copper or copper alloys (brass or bronze). Of course, gold is also yellow; but because of its cost, it is not found in most products.

Aluminum is silvery and quite light as is magnesium, but magnesium not too common. Zinc is not as common as it was before plastic began to replace it; however, zinc coatings are common on steel nails, sheet metal and brackets. Often, plating of parts with zinc, cadmium, copper and brass leads you to think that the parts are solids of the plating material. A magnet will usually show the parts to be made of steel.

Once you have made an educated guess of the material, do some research in reference books to determine favorable properties of each material to help see why the material was selected for the part you found. Next, mount these objects on posterboard with labels to identify the materials and giving the properties which probably caused their selection.

With this background you now are a more intelligent consumer and user of materials. If you become aware of metals and other materials in the world around you, it becomes fun to ask questions of why one material was chosen over another and make up your own mind about the suitability of materials.

This information can help you in making personal purchases and is important in many jobs. Look further into references about metals, investigate the career opportunities, and be conscious of materials you chose and use.

Math/Science/Technology Interface

Materials science is interdisciplinary using concepts from physics, chemistry and engineering. Metallurgy is a branch of materials science and engineering. As we have seen in this module on metallic materials, the internal structure of metals influences their properties.

Subatomic structure is not observable, but atomic and nuclear physicists conduct experiments to gain greater knowledge about how the elements of an atom's structure interact to cause specific properties. Some structures of metal, such as grains, are observable with a metallurgical microscope; but other structural aspects cannot be seen, rather we observe changes in the material which indicate internal structural changes.

In an earlier segment of this module you were introduced to a iron-carbon phases diagram and told how such diagrams help heat treaters determine the internal space lattice structure of iron and steel. The following is but one of many rather simple heat treatment experiments to demonstrate the importance of carbon content and temperature on steel properties. Others experiments can be found in references on metallurgy.

Objective—To observe results of structural changes in steel.

Materials

- Small bar magnet
- Flame torch
- Steel wire 12" long
- Two 16-penny common nails
- Board to drive nails about 10" apart

Procedure—Wrap the wire around the nails and allow bar magnet to attach to wire. Turn lights down low. Use a flame torch to heat the wire to glowing color. Can you observe any color changes in the wire and any change in the action

of the bar magnet? See if the magnet will reattach to the wire.

Discussion—You should have observed color changes in the steel which can be matched to a color chart in metallurgical books to indicate temperature ranges where space lattices change. Heat treaters use these colors or they employ pyrometers to determine when to cool a part in water or other cooling medium.

The temperature obtained and rate of cooling will determine the material's hardness or toughness. Adequate carbon must be present in the steel to achieve high hardness. The fact that the bar magnet dropped off the wire was another indication of internal structural change; however, the loss of ferro-magnetism in the steel is only temporary at the elevated temperature. At a temperature of about 1,418°F (770°C) iron loses its ferromagnetism. This is referred to as the Curie temperature T_c). The magnet attaches again to the cooled wire.

Summary

This module has introduced you to the very broad field of metals technology. While metals face competition from the other main groups of materials (polymers, ceramics, and composites), we will always need metallic materials; new developments will continue to advance metal as a key engineering material. Hopefully, you will continue to learn about metals and all material because you will be helping yourself and society with this knowledge.

Quiz

1. What are some benefits of gaining knowledge about metallic materials and engineering materials technology?
To become a more informed citizen, a wiser consumer, and explore career possibilities
2. What is the difference in the terms metals and metallic materials?
Technically, metals are only the metallic elements while metallics include metal elements and metal alloys, but metals commonly is used synonymously for both alloys and metal elements.
3. What determines the properties that a metal possess? *internal structure*
4. What is steel?
An alloy of iron, carbon and other elements
5. Name one ferrous metal and two nonferrous metals.
Many possible: ferrous—50% or more iron e.g. cast iron, stainless steel; nonferrous—aluminum, copper, tin, zinc, silver, etc.
6. What happens to the structure of iron as it is heated higher and higher but still in the solid state temperature range?
Phase changes of space lattices at room temperature from BCC to FCC at 910°C then back to BCC at 1400°C
7. How do heat treaters know what temperatures and carbon percentages will change steel properties?
Phases diagrams
8. What are PM products?
Particles of metal and other elements that are pressed together than sintered
9. What are superconductors?
Materials which offer no resistance to flow of electric current.

Possible Student Outcomes

- Recall career opportunities in engineering materials technology and the value of studying about metallic materials.
- Define and differentiate among the following: metal (ferrous and nonferrous), phase powdered metal, superconductors, steel, cast iron.
- Describe the internal structural changes that occur in iron as it is heated.
- Cite some examples of uses for ferrous and nonferrous metals.

Acknowledgements

Figure 1—reprinted with permission, copyright Walt Disney World Productions, 1982.
Figures 2 to 6 and Table 1, reprinted with permission, James A. Jacobs & Thomas F. Kilduff, *Engineering Materials Technology*, Prentice-Hall, Inc. Englewood Cliffs, NJ, 1985.
Figure 3—courtesy Joseph P. Neville, Wentworth Institute of Technology.
Figure 7—courtesy Institute of Materials Science and Engineering, National Bureau Standards.
Figure 8—courtesy of Flow Systems.
Figure 9—courtesy National Aeronautics and Space Administration.

References

Jacobs, J. & Kilduff, T. (1985). *Engineering Materials Technology* Englewood Cliffs, NJ: Prentice-Hall.

Glasgow, T. et.al. (1987, July/August). Rapid-Solidification processing facility. *NASA Tech Briefs*, p. 54.

The Aluminum Association.(1987, Spring). Quick-frozen alloys. *Aluminum Development Digest*, pp. 1 & 2.

Fischer, A. (1987, July). Superconductor frenzy. *Popular Science*, pp. 54-58, 97.

Heppenheimer, T.A., (1987, July). Superconducting—the new billion dollar business. *High Technology*, pp. 12-18.

Resources in Technology

Intermodal Transportation

FIGURE 1
An overhead crane loads and unloads containers onto flatcars at the Intermodal Transfer Facility in southern California. Note the specially built container hauling trailers in the foreground. (Credit: Southern Pacific Transportation Company)

Resources in Technology is written and prepared by Tidewater Technology Associates (T2A), an educational consulting group that specializes in the development of technical programs, curriculum and instructional materials. Members of the group are John M. Ritz, Walter F. Deal, III, Fred Hadley, James A. Jacobs, Thomas F. Kilduff, and K. George Skena. Further inquiries can be made by contacting John M. Ritz, 5316 Marlinton Drive, Virginia Beach, CA 23462; 804/440-4307.

Intermodal transportation is the planned and coordinated movement of people, products, and goods using two or more means of transport. For example, goods manufactured at an inland factory might be transported by truck to a railroad terminal for shipment to a port where they are to be placed on a ship bound for an overseas port. Upon reaching the shipping port, the products might then be off-loaded onto another truck for movement to a warehouse to await ocean transportation or be loaded directly onto a ship. The intermodal transportation movements of the products presented in this scenario are very commonplace in today's complex world marketplace.

Intermodal transportation has emerged as one of the most practical approaches to the movement of goods. In many cases, it is the only pragmatic method available. During this study of intermodal transportation, you will become familiar with several new terms. These include containers and containerization, piggyback operations, shrink wrapping, unit loads, and others. Each of these terms is an integral part of the field of intermodal transportation. As you begin to read about these terms, refer to the glossary which accompanies this article when necessary.

Several factors must be considered by

FIGURE 2
A container loaded with cargo is shown here being off-loaded from an ocean going vessel onto a specially manufactured truck which will be used to transport it further. A large container handling crane may be seen in the background. (Credit: U.S. Dept. of Transportation)

a people-mover, manufacturer, or other producer when selecting the types of transportation which will be best suited to the firm's products. During this study of intermodal transportation, remember that people are considered to be a cargo. For instance, an airliner loaded with passengers is carrying a cargo of people. The same is also true of a passenger train on a railway.

A complete study of the entire field of freight and cargo movements, operations, cost factors, etc. is far beyond the scope of this brief article. However, later we will examine the relative advantages and disadvantages of the various types of transport which might be used during intermodal movements.

While it is important for you to understand the meaning of intermodal transportation, it is of equal importance that you know what it is not.

Some of the types of transportation capable of operating in more than one field of transportation (i.e. terrestrial, marine, atmospheric, and space) do not necessarily always engage in intermodal transportation. For example, while a hovercraft may be used to transport containerized cargoes, it may not always carry such intermodal types of loads. As has already been stated, intermodal transportation does not actually occur unless the movement of the cargoes carried by different modes is accomplished in a planned and coordinated manner between two or more types of transport.

Further, the shipment of cargoes by two or more means of transportation does not necessarily indicate that true intermodal transportation has occurred. By examining its stated definition, you can see that proper planning, coordination, and cooperation between different modes is a requirement for intermodal transportation. Sending Product XYZ on a train and later placing it on a truck for delivery to its final destination without coordinating loading, departure, and delivery times is not true intermodal transportation.

FIGURE 3
Because this hovercraft can operate in both land and marine environments, it is readily adaptable to intermodal transportation operations. Two large shipping containers are shown here being ferried from a ship to a storage facility on shore. (Credit: U.S. Army)

Contemporary Analysis

Shippers who choose to use intermodal transportation for the movement of their cargoes can benefit in several ways. Generally, shipping rates are more favorable to intermodal users. Additionally, considerably less paperwork is generated for users. Usually only one billing for shipping charges is required, rather than one from each separate mode used. A further and considerable benefit to the users of intermodal transportation methods is the relatively complete and efficient physical facilities usually available for handling the interchange of cargo between modes.

Types of Transportation

Let's look for a moment at the types of transportation which may be a part of the intermodal movement of cargoes. As we do so, we'll look briefly at some of the advantages and disadvantages of each type, remembering that intermodal transportation attempts to maximize the advantages of each while minimizing the effects of its disadvantages. The types of transportation which we will examine are trucking, railroads, airlines, and waterborne modes, such as ships and barges.

Trucking

Because of their unique operating characteristics and the over four million miles of highways available to them, trucks play an extremely important role in the transportation system of this nation. While trucks very often begin and end the transportation operations of other modes (i.e., pickup and delivery), they are seldom dependent on those modes for their operations. The relatively small loads carried by trucks (i.e., one or two containers in the case of

FIGURE 4
This extensive new electronic freight classification yard utilizes many new technological developments to improve the movements of good through it. It was recently constructed at a cost of over $48 million. (Credit Southern Railway Corp.)

FIGURE 5
Trucks carry about 25% of all the ton-miles shipped in the United States. The Intermodal Container Transfer Facility in southern California serves the ports of Los Angeles and Long Beach—the west coast's two largest ports. During its first year of operation, the facility handled 320,000 containers and is expected to handle 360,000 in 1988. The 150-acre facility is 1.3 miles long and the width of two football fields. (Credit: Southern Pacific Transportation Company)

FIGURE 6
This unit load of steel pipe may be most efficiently shipped over the majority of its journey by rail. At the journey's end, final transportation may be by truck. This load, 115,000 tons of 36-inch diameter pipe, will be used to construct 320-miles of an 800-mile natural gas pipeline from western Wyoming to eastern Nebraska. (Credit: Bethlehem Steel)

intermodal transportation) are usually moved quickly to their destinations without interruption. Trucks carry about 25% of all the ton-miles shipped in the United States.

The costs involved in operating the trucking industry are quite small when compared to those of other modes. The cost for a new tractor-trailer rig may be from $100,000 to $200,000, while a cargo ship or aircraft may cost millions of dollars. The costs to shippers using trucks may be high per ton-mile, but advantages such as geographic availability and relative accessibility outweigh or justify the costs involved.

Railroads

Although the use of railroads for shipping is declining in this country, they still haul more ton-miles than any other type of carrier. Because of their extensive use (especially in the shipment of coal and other raw materials), they also play a major role in the nation's transportation system. Trains can carry very heavy and large loads over great distances at a relatively low cost. Very long coal trains, which are a common sight in many areas of the country, are clear evidence of this.

In comparison to other modes of transportation, railroads are fairly near the middle of the spectrum in speed of delivery. While they are not as rapid as trucks or aircraft, they are considerably faster than waterborne modes of transport.

An interesting aspect of railroads is that all of their equipment is standardized. For example, freight cars or diesel engines from one line will operate on the lines of another railroad and the coupling of cars from various lines presents no problems.

FIGURE 7
This artist's concept shows a cargo-carrying spacecraft which will be used to transport people and payloads directly from the Earth's surface to orbiting space stations. Because of the very high costs involved, the maximum utilization of all available cargo space will be mandatory. (Credit: NASA)

FIGURE 8
From the pilot house of a towboat this mixed tow of grain and coal seems to stretch into infinity. (Credit: American Commercial Lines)

Aircraft

The growth of the air transport industry has only begun to flourish in the past few decades. It has now emerged in proportions that make it an important part of our large transportation system. Although it is comparatively expensive and the volume shipped is relatively small, the transport of cargo by air is very rapid. Highly perishable materials as well as emergency supplies are often shipped by aircraft.

Much special handling equipment has been developed to support this growing transport industry. Many cargo-carrying aircraft use containers shaped like the cargo compartments of their aircraft in order to obtain maximum space utilization.

Waterborne

At one time, the shipment of freight was mainly by water. This was because of the availability of this country's vast network of rivers, canals, lakes, and its extensive coastline. Although its use has diminished, water transport still accounts for about 23% of all the ton-miles shipped in this country.

The majority of our major commercial centers may be reached by water. The costs to transport goods over water are extremely low and tremendous amounts of bulk cargo may be moved over it at one time. The slow speed of water transport and its somewhat restricted travel network are factors limiting a more extensive use of waterborne transport.

People

Although discussions of intermodal transportation generally relate to the movement of freight or products, people themselves are also a cargo which may be moved using intermodal means. For example, groups of people may be moved to various locations within an airport terminal area by moving sidewalks. These people movers may deliver them to some other form of personalized rapid transit (PRT) system (see "PRT—The Way To Go!," *The Technology Teacher*, January, 1986, pp. 15-22), such as the Airtrans System used at the Dallas-Ft. Worth Airport. Such systems are common at airports today.

Upon reaching their desired destinations on the automated (operator-less)

Airtrans System, the cargo of passengers may be shuttled out to a waiting aircraft by some special form of busing. By the time the passengers are seated and the aircraft leaves, the cargo of people will have been moved by at least four types of transport, possibly more, just within the terminal area.

These modes have been planned and coordinated to deliver their cargoes in a timely and efficient manner. While the people in the example above are not technically containerized, they have been kept together as a group headed for common destinations.

Elevators, Escalators, and Conveyers

The movement of people, freight, products, and other cargoes or loads may also be accomplished using elevators, escalators, and various types of conveyers. Each of these modes can be utilized in combination with others to assist in delivering cargoes to selected locations. Conveyer belt systems are used to move items as diverse as baggage in passenger terminals and coal. Escalators move from level to level carrying people, and elevators may move cargoes and people. The use of chain-drawn carriages or rollers on an assembly line during the manufacture of some vehicles is a planned movement of products which will later be moved or transported by other means. All of these are a part of the planned and coordinated use of intermodal means of transportation.

By combining the best or most advantageous characteristics of each of the foregoing modes of transportation into one movement or shipment, intermodal transportation is created. The use of it will help to ensure that cargoes arrive at their designated destinations with a minimum of delay, in the best possible condition, and in the most efficient and cost effective manner practical.

Materials Handling

The procedures, materials, and equipment shippers presently use in the management and handling of their cargoes have helped to make the widespread implementation of intermodal transportation a practical reality. Although materials handling does not add to the value of a product, it is usually a significant element of its selling cost. This added cost to the consumer may be as high as 20% to 35% of the cost for manufactured goods and even more for agricultural products. A complete study of materials handling would be much too broad and technical for this article, but several factors related to it are specifically important to intermodal transportation. With this in mind, let's take a look at a few facets of materials handling.

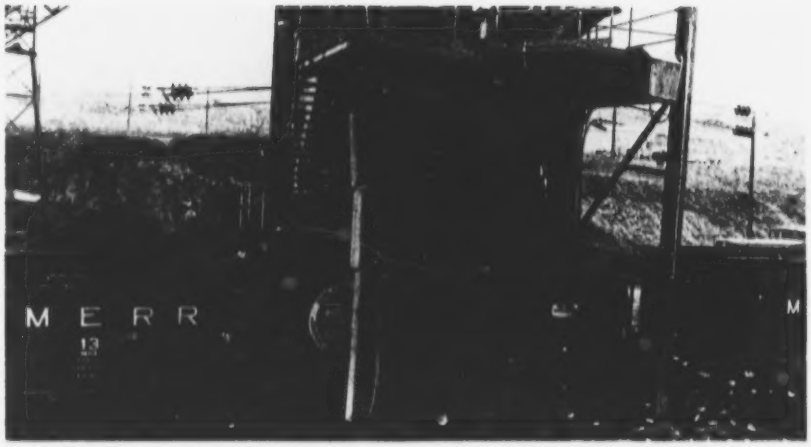


FIGURE 9
This coal train is being loaded through automated chutes. Once the coal has been transported to another location and washed, it will be moved overland by conveyer belt to the Ohio Power Company's Muskingum River Plant where it will be used to produce electricity. (Credit: AEP Fuel Supply Department)

Procedures

There are three basic procedures in materials handling. They are 1) picking up the load, 2) transporting, and 3) setting it down. The special materials and equipment required may sometimes be used for more than one of these procedures. For example, the same type of rail-mounted gantry which is used to load containers onto railroad flat cars at the beginning of a shipment may also be used to unload them at its end. When developing procedures to handle intermodal transportation, some considerations which must be incorporated into them are:

- Unit load concept (to include containerization)
- Safety
- Security (pilferage, etc.)
- Types of required equipment
- Appropriate packaging/shipping materials
- Protection against natural elements (weather)

Materials

Many standard stocks are used in materials handling. Steel strapping for banding, plastic sheeting for wrapping, lumber for pallets, and corrugated cardboard for containers and padding are typical.

One procedure which is very appropriate for many intermodal shippers is called *shrink wrapping*. This procedure uses thin plastic fiber materials, manufactured in a stretched sheet form which is placed on large rolls. After a cargo is covered or loosely wrapped with it, heat is applied. The approximately 300° to 400°F of heat causes the plastic material to shrink back to its normal size, thus tightening the wrapping around the cargo.

The consumer's concept of shrink wrapping is usually developed from seeing small packs of nuts and bolts or other miscellaneous items in a retail store which have form fitting, difficult to remove plastic fitted over them. In the bulk shipment of cargoes, however, entire loads or pallets of items may be covered using shrink wrap methods. Products as diverse as cases of soda water and bricks may be covered in this manner.

Shrink wrapping offers many advantages to shippers. Here are just a few:

- Transparent (the contents are visible)
- Negligible weight (does not add to the weight of the cargo)
- Load stability (resistance to shifting or tipping)
- Dust proof
- Weather-proof (materials may be stored in the open)
- Less damage to cargoes than when steel bands are used

Another procedure, *stretch wrapping*, which also uses clear plastic sheeting as a covering material, offers most of the same advantages as shrink wrapping but also costs less. The plastic material, which is stretched around the cargo,

FIGURE 10
Old-time locomotive engineers wouldn't recognize this—a memory module for Union Pacific System's new SD60 diesel-electric locomotive computer control system. The computer will assist engineers in getting maximum efficiency from the locomotive. (Credit: Union Pacific)

cannot generally be used to cover the tops and bottoms of cargoes effectively, a factor which limits the uses of stretch wrapping.

Equipment

A very wide variety of materials handling equipment is needed to meet the requirements of intermodal transportation. Various sizes of overhead cranes, forklifts, etc. are utilized because of the variety of loads which are transported. In addition to the types of equipment usually required to lift and move cargoes, much special equipment is also required. For example, when unit sized loads are made up, very large, specially manufactured shrink wrap machines may be used.

Some other types of specialized equipment which may be used during intermodal transportation include:

- Container handling trucks
- Shipping containers of various sizes (for example, sea-containers which are 8′ × 8′ × 20′ (or 27′, 35′, etc.)
- Aircraft cargo containers designed in the shape of the aircraft's interior to utilize all available cargo space

Special railroad cars have been developed to increase the volume of cargoes which may be shipped simultaneously from ports of arrival to inland destinations. These special shipping cars use a two-tiered system of loading containers. In January, 1985, the Southern Pacific Transportation Company successfully initiated a two-tiered train run between the port of Los Angeles and Chicago. The service could accommodate 120 containers up to 40′ long. A similar service from Oakland, Calif., had begun in July, 1984, with comparable satisfactory results.

One final type of special equipment which must be included in this discussion is the computer and its related communications technologies. Computers are used to control operations, coordinate loads and loading, schedule arrivals and departures, monitor movements, and to aid in countless decisions that must often be made very rapidly.

Social-Cultural Impacts

A more extensive implementation of intermodal transportation practices could help to control some of our nation's transport problems. One of the largest and most significant of these is the major traffic congestion in the majority of our urban areas—particularly during rush hours and other peak traffic periods like holidays. Another important problem directly related to transportation by automobile and trucks is air pollution.

The congestion and pollution caused by the millions of vehicles on our highways could be better addressed if more for-hire modes of mass transit (see "Movin' On With Mass Transit," *The Technology Teacher*, February, 1985, pp. 19-26) and intermodal transportation were used by businesses and commuters. Various forms of PRT (personalized rapid transit) could be used to enter and exit urban areas while private automobiles could be left at outlying commuter parking lots.

More attractive fare rates and more favorable government regulations could be used to encourage the use of more intermodal transportation. Commuter airlines are already experiencing some successes in making commuter fares a more desirable feature of business air travel.

Intermodal transportation methods can greatly increase the efficiency of our transportation system if they are properly and more widely implemented. Larger volumes of people and other cargoes may be transported with less effort, dollar cost, and congestion, with a diminished energy expenditure. Ultimately, the use of intermodal transportation results in savings for consumers. Although initially transportation costs are absorbed by a cargo's shippers (i.e. people mover, manufacturer, cargo forwarder, etc.), they will eventually be passed on to the buyers of the product or service.

MODE OF TRANSPORTATION	Airlines	Railroads	Trucks	Water Borne
Relative Costs	Very high	Low	High	Very low
Speed of Operation/Delivery	Fastest	Slow	Fast	Very Slow

TABLE 1
A Comparison of Various Modes

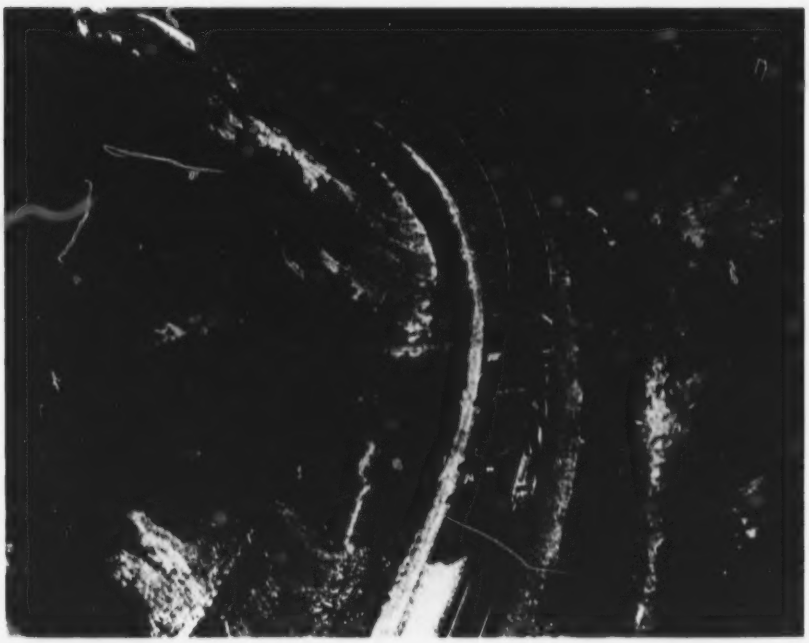


FIGURE 11
Railroads frequently use the unit load concept when making up trains such as the long coal hauler shown here. These trains are a vital link in the intermodal operations of our transportation system. (Credit: Southern Railway)

Construction Activity

You have seen how important intermodal transportation methods can be to both shippers and consumers. In this issue of "Resources in Technology" you have also learned about many of intermodal transportation's important elements.

In this activity, you are to plan, design, and construct a three-dimensional model of an intermodal transportation facility. During the planning process, discuss the relative merits of different suggestions with other members of the group. Decide on one or two types of facilities to be constructed.

Using drafting equipment, draw plans for the proposed facility. Discuss the plans with a partner or the entire group. Make modifications as required. Following the planning and design stages, construct the model using materials found in a technology lab. Some examples:

- You might choose to construct a rail mounted gantry crane similar to the types used to place large containers on trucks.
- You could build a model of a railroad loading terminal or piggyback operations.

In preparing for your activity, use information sources from outside the school environment such as local libraries or businesses which are engaged in intermodal transportation (i.e. local airlines, railroads, trucking firms or other companies).

Math/Science/Technology Interface

Many of the problems encountered daily by intermodal transportation users may be solved through the application of basic mathematics. This relationship is clearly shown in each of the following examples:

Example One—Shippers must know how much available space there is within an aluminum shipping container which measures $8' \times 8' \times 40'$. This is easily calculated using the formula:
width × height × length = cubic feet available. Abbreviated this is:
$w \times h \times l$ = feet or
$8 \times 8 \times 40 = 2{,}560'$.

Example Two—A 233-car coal train is available to move 20,000-tons of coal. Load planners must calculate the carrying capacity of the train and compare it to their needs. In the 1980's, an average rail car could carry 80-tons of coal. By multiplying that times the number of cars, the train's total capacity, which is 18,640-tons, is readily found. The train available to the shippers will have to haul an additional 17 cars since it is 1,360-tons short of carrying capacity.

Example Three—An aircraft carrying containerized cargo must carry sufficient fuel for its planned flight for its own weight plus the added weight of the cargo. The rate at which the fuel will be consumed at certain speeds and altitudes must be calculated.

These simple examples are similar to the thousands of facts that must be determined each day by our nation's shippers. In all types of intermodal transportation, users must know how much energy will be expended for a certain movement of goods and the resultant cost.

Summary

During this brief overview of intermodal transportation, you have learned that it is a very important part of the transportation system. Many tons of goods and other cargoes are shipped annually by land, marine, atmospheric, and even space modes of transportation. By skillfully arranging shipments to take maximum advantage of the modes available to them, shipments are delivered faster, more securely, and much more economically.

A more widespread use of intermodal transportation methods could help to alleviate many of our country's pressing traffic needs. Two of these are congestion in the air and on land, and a reduction of pollution levels.

Glossary

Banding—The wrapping of a cargo with band of steel or other material to stabilize the load.

Container—A unit inside of which items of cargo are packed. In such a unit, small items may be consolidated into a larger load for shipment.

Containerization—A system for the shipment of products/goods based on large cargo carrying containers which can easily be interchanged between different modes of transportation without rehandling the contents.

Container-On-Flat-Car (COFC)—The transportation of an ocean shipping container on a railroad flatcar.

Gantry Crane—A type of cargo lifting device used both indoors and outdoors, with a wide variety of applications including dockside use, manufacturing, and service.

Interstate Commerce Commission (ICC)—An independent agency of the federal government which regulates the rates and trade practices of companies which transfer goods and passengers between states.

Intermodal Transportation—The cooperation and coordination of two or more modes of transportation in moving a single shipment, taking advantage of the best characteristics of each.

Pallet—A shipping platform, usually wood, which may be easily loaded and then handled by special equipment, such as forklifts.

Personalized Rapid Transit (PRT)—The use of high speed, electronically operated vehicles to transport from 3 to 12 people simultaneously.

Piggyback Operations—The transportation of highway trailers on railroad flatcars. Ocean going types of containers may also be incorporated into these operations.

Shrink Wrapping—A method of heat treating loads wrapped with thin plastic films making them secure for shipment.

Stretch Wrapping—A method of securing cargoes by wrapping them tightly with a thin plastic film.

Ton-mile—The movement of one ton of freight one mile.

Trailer-On-Flat-Car (TOFC)—The transportation of a highway truck trailer on a railroad flatcar.

Unit Load—The combining of many packages or units of an item (such as railroad coal cars) into one shipping container or load so all may be handled at one time.

Vehicle Load Shipment—A load which fills the entire vehicle to capacity and which does not require any rehandling during shipment so it can move directly from shipper to receiver.

Student Quiz

1. What are some advantages of intermodal transportation?
2. Name some factors shippers must consider when using intermodal transportation.
3. How may people utilize intermodal transportation to meet their personal transportation needs?
4. Explain how containers help to reduce the chance of loss or damage to cargoes.
5. What are some economic advantages of containerization?
6. What is shrink wrapping? Name some advantages of using it.
7. Why do you think the high costs of some special handling equipment can be justified in intermodal transportation?
8. Discuss why trucks are often used to begin and end shipments made using other modes of transportation?
9. Since our waterways are extensive, it would seem very practical to ship many more types of goods by ship or barge. Why not?
10. Explain why a shipper might choose to ship cargoes by air.
11. List some reasons why railroads are the most practical way to ship some loads.

Possible Student Outcomes

- Describe the concept of intermodal transportation.
- Describe the concept of a unit load.
- List and explain some of the elements of intermodal transportation.
- Explain containerization and its applications.
- List and describe some of the materials and equipment used in the packaging and handling of products.
- Associate mathematics and science as an integral part of the study of intermodal transportation.

References

Allegri, T.H. (1984). *Materials handling*. New York: Van Nostrand Reinhold.

Bowersox, D. J., et al. (1981). *Introduction to transportation*. New York: Macmillan.

DeOld, A. R., et al. (1986). *Transportation*. Worcester, MA: Davis.

Haeiner, L. E. (1986). *Introduction to transportation systems*. New York: CBS College Publishing.

Moving on with mass transit. (1985, February). *The Technology Teacher*. pp. 19-26.

PRT—the way to go!. (1986, January). *The Technology Teacher*. pp. 15-22.

Probst, L. A. & DeGross, K. (1979). *Transportation dictionary*. Gaithersburg, MD: Data Tactics.

Sampson, R. J. & Farris, M. T. (1975). *Transportation*. Boston, MA: Hoghton Mifflin.

Story, G. (1985, July 11). Intermodal service launched from oakland. *The Journal of Commerce*. p. 7A.

Watson, R. (1985). (1985, January 9). Sealand and southern pacific to start a 2-tiered train. *The Journal of Commerce*. p. 1a.

Resources in Technology

Food Production

Contemporary Analysis

The efficient production of food has been a major liberating factor for developing and developed societies. Freed from the necessity of gathering or raising food and food crops, individuals and groups within societies could purse other activities. These activities could include the manufacture of clothing and furniture, the construction of homes and factories, the processing of chemicals, the writing and publication of books, and the transport of people and cargos.

Today only three countries—United States, Canada, and Australia—produce more food than they can consume. Other nations must import food to supply the demands of their populations. Yet the United States, with only five percent of the world's population, consumes one-third of the world food resources. What must take place for societies to produce the food to feed the world's populations.

Food can be obtained and processed through various means. Natural methods include raising crops such as tomatoes and wheat. Livestock, poultry, and fish may also be raised naturally (Figure 1).

Some food products may also be produced synthetically using chemicals and natural products. Margarine, candy, pies, cakes, and beverages are processed using both chemicals and natural ingredients. In recent years biotechnological methods (use of living organisms) and genetic engineering are aiding in the production and processing of food products. These methods will probably contribute significantly to the future production of food products as the world population continues to increase.

After seeds and plants are raised and animals mature they must be gathered so that further processing can occur. We rely heavily on a very small percent of the population—farmers—to take care of these chores for us. Today only about 2½% of the United States population is employed as farmers.

Harvesting

The process of gathering food resources is referred to as harvesting. In developed societies much chemicals and energy resources are required to raise our crops. The chemicals replace the nutrients taken from the soil from years of farming and the energy resources are required to till the soil, spray fertilizers and insecticides, irrigate the crops during dry seasons, and harvest the food when it is mature.

Harvesting is also used to categorize the operations of gathering poultry, livestock, vegetables, fruits, grain, and fish

FIGURE 1
Today animals are raised in controlled environments. This enables farmers to produce healthier livestock.

so that they may be further processed for human consumption. Fish are a prime source of protein for the world's population. Although some species are caught by individuals to provide a food source for their families, most fish are taken commercially and sold through supermarkets.

Special methods have been developed to harvest fish. These include using boats and ships and are referred to as trawling, purse seining, gill netting, and long line fishing. Shell fish such as shrimp are harvested by trawling while crabs and oysters are often gathered by dredging. In recent years fish farming has become a viable method of raising seafood and fish to meet growing demands. In the U.S. raising catfish in ponds is a profitable business. Experimentation is also proving successful for the farming of shrimp, oysters, and lobsters.

In addition to fishing, meat from livestock and poultry also needs to be processed so we may use it as a food source. Cattle, hogs, and chickens are prime food stocks of meat packing in the United States and Canada. Hogs and poultry are big consumer meat products in Western Europe. After the animals are bred and raised to maturity, they are sold by the farmers. The livestock is moved to the meat and poultry packers by rail and trucks.

Prior to harvesting, much research takes place in the animal sciences to breed healthy and meat producing livestock and poultry. Universities study alterations in genes, animal diets, and environments to produce breed stock that may gain more meat weight so that farmers can raise animals quicker and increase their profits. Agricultural and biotechnological research will continue as farmers must produce better yields to feed the increasing populations of the world.

In raising animals, various breeds are raised in various locations. Climate and soil play a large part in these decisions. Milk spoils easily if not handled correctly. It is usually produced near larger cities. Cattle need a lot of grazing area so are usually raised in the plains areas of the U.S. and Canada. Sheep are raised primarily for their wool. The market for wool does not need to be near the sheep. Poor pasture will do. The world leader in wool production consequently is Australia.

After the animals are bred (artificial methods are used extensively), they are raised on farms. Their diets are managed so that they mature earlier and produce the most meat at the cheapest possible price. Prior to sale and slaughtering, many cattle are brought to feedlots where grain and meal are fed to them to increase their meat per carcass ratio.

When beef cattle are processed, their meat usually weights 55% of their total weight. With special diets this ratio can be increased to as much as 65%. These same feeding practices are also used with hogs and poultry to increase their yields.

Plant crops are also harvested prior to processing into food products. As with animals, scientists have improved crops by varying their characteristics through research methods. The genetic structure of seeds and plants have been altered to produce plants that can survive in different climates and produce larger yields. This research has involved species of corn, rice, fruits, tomatoes, etc. You have probably seen examples of hybrid tomatoes, cucumbers, apples, oranges, etc. Scientifically they can be bred to look better, taste better, and resist certain insects and diseases.

After fruits, grain, and vegetables are grown, they must be harvested for further processing. Wheat must be gathered for processing into flour and cereal; tomatoes for tomato sauce, soup, and ketchup; fruits for pie fillings, jellies, and juices; and so on.

Some vegetables must first be dug from the ground before they can be picked. Examples include potatoes, carrots, beets, and peanuts. Specials plows and pickers have been designed to turn the soil over and not damage the food products.

After these products are exposed they may be picked like other fruits and vegetables. Two means exist for picking or harvesting plant products. These include manual and mechanical methods. Traditional and still heavily used are the manual methods.

Migrant workers pick much of the U.S. food crops. The migrants travel up and down the East and West Coasts to pick fruits and vegetables as they ripen. This manual picking is time consuming and costly. Farmers and corporations must plan to have the migrant workers at their farms when the crops are ripe. This requires scheduling and logistics to support the workers as they harvest the crops. Housing, transportation, and meals must be provided.

Because of the time, cost, and logistics required for manual harvesting, mechanical harvesters have been designed and developed. One of the first mechanical harvesters invented was the reaper. It would cut fields of wheat much quicker than a human with a sickle.

Since the invention of the reaper, many other harvesting machines have been developed. This includes the combine (harvests and also separates the wheat from the stock), corn picker, peanut picker, and many others. There are specialized harvesters for cucumbers, soybeans, and hay. Experimentation has led to the invention of specialized harvesters to pick grapes and even shake apples from the trees into collection aprons.

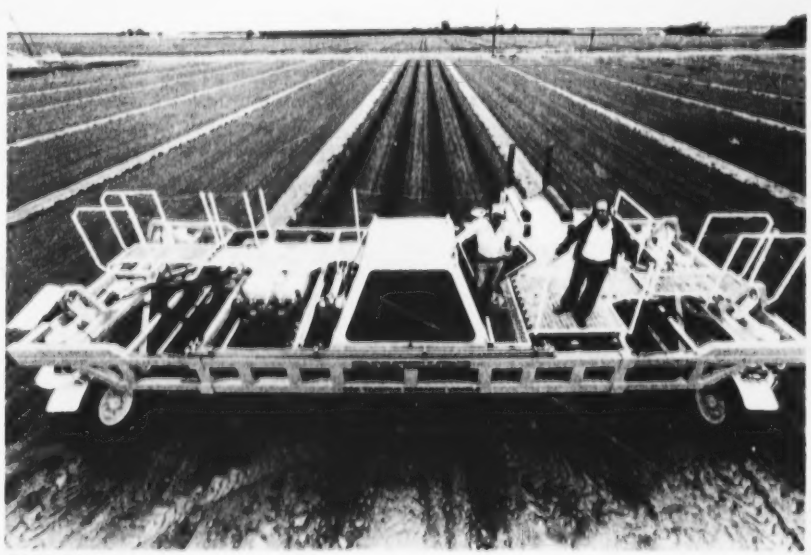


FIGURE 2
A wide tractive research vehicle is being developed to improve tilling methods.

Modern technology continues to change the way farmers raise our food crops. Current experiments are underway with vision robots to scan and pick only oranges that have ripened. Figure 2 shows an experimental tractor that can be used to cultivate wide areas of land without compacting the soil.

After harvesting, industry takes over to process our food resources for human consumption. Apples may need to only be washed, waxed, sorted by size, and packaged, while wheat must be separated from the chaff, sorted, ground, enriched, and packaged. Tomatoes might need to be washed, sorted, crushed, cooked and combined with spices before they are bottled as ketchup.

These operations usually are not brought into the technology education curriculum, but are vital industries and processes to be studied in a technological world. The overall operations involved in the processing of food products may be classified as reduction in size, separation, combining, conditioning, and forming. Not all operations need to be done to all food products for them to be consumed or preserved.

Reduction in Size

Although the processing of food does not happen always in a precise order, food products are usually first reduced in size and then separated. This often is done to reduce the products to sizes that can be handled by workers and to sort out waste products. Waste products are removed such as stems, skins, cobs, carcasses, scales, and bones and organs.

After the wastes are removed (much of the initial wastes are processed into other products such as animal feeds and fertilizers, leather goods, and chemicals), the products are sorted and graded. The Department of Agriculture has set standards for grading to assure the public that they are receiving quality products free of wastes and other substances that could be harmful to their health.

Did you ever look on a processed packaged bakery product and read "Reg. Penna. Dept. of Agr." This stands for "Regulated by the Pennsylvania Department of Agriculture" which dates back to 1933. It certifies that the bakery product is sanitary and meets the standards of the Commonwealth of Pennsylvania. It does not pertain to food additives or chemicals.

Reduction in size includes processes such as cutting, crushing, and grinding. These prepare the foods for further processing. The stocks are cut off of corn and wheat, fish are scaled and filleted, oysters and clams are shucked, while cattle and hogs are slaughtered.

Separation

After food resources are reduced in size, they are often separated to remove impurities and other wastes. Separation may involve such operations as trimming, filtering, sorting, sifting, drying, refining, and distilling (Figure 3).

In meat processing, bone and fat may be trimmed from the meats or chickens may be quartered. Apples and eggs are sorted for grading and removal of unfit products. Coffee beans are ground while milk is pasteurized and homogenized. Sugar is refined to separate liquid sugar, syrup, and granulated sugar. Concentrated orange juice is made by removing the water from the juices that are separated by crushing. Water and heat are often used in separation and cleaning processes.

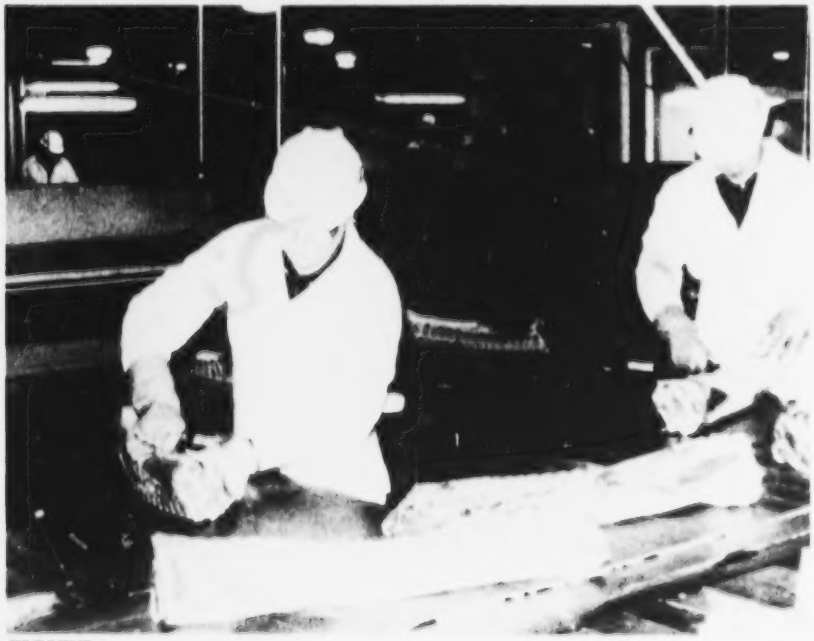


FIGURE 3
Meat packers trim pork loins to prepare them for further processing.

Combining

Another group of processing operations is referred to as combining. These involve mixing and blending of food resources and additives such as coloring, preservatives, spices, and emulsifiers. Hamburger is made by mixing fat with low grades of beef. Sausage is made by combining of pork, fat, and spices. Jello™ is made by combining gelatin, sugar, coloring, and flavorings. Applesauce is made by combining crushed apples, corn syrup, and water. Peanut butter combines peanuts, dextrose, hydrogenated vegetable oil, and salt. Many cereals contain a host of grains such as rice, corn, and wheat plus such ingredients as sugar, salt, corn syrup, and flavorings. (As you see many products have sugar added to them. Although sugar may not be the exact ingredient it is contained in such ingredients as dextrose, glucose, and corn syrup.)

Often one of the types of items combined with food is an additive. These natural and synthetic substances do many things to foods. A section later will examine additives in depth.

Conditioning

Following combining operations many food products must be conditioned. Conditioning involves heating and cooling to make the products more usable. Food products such as beans, milk, and canned meats are precooked to condition them for storage. Cucumbers and herring are pickled to make pickles and pickled herring. These are conditioning operations. Fruits can be dried to condition them for later use. As a result we get raisins, dates, figs, and dried apricots.

Other food products are conditioned by cooling. Coffee can be freeze dried and fish and vegetables are quick frozen for storage purposes. Many dairy prod-

ucts must be kept cool so that they will not spoil.

Forming

A final food processing operation is forming. Not all food products are formed. Many are just canned or packaged. However some products need to be formed. Candies are often molded such as fruit tarts and chocolate bars. Cakes and breads are formed in their baking pans. Noodles and other pasta products are rolled or extruded to give them their shapes.

In addition many processed meats (those made of ground/chopped parts) are formed to give them an appealing shape. Pressed ham, chicken nuggets, and chopped steak are examples of formed processed meats. They are usually formed for convenience of use, customer appeal, and handling.

"Badditives" or "Additives?"

Today it is very hard for to tell exactly what is in a food product. This is because so many chemicals are used as additives and preservatives in the processing of our food products. For example, a can of vegetable beef soup can contain water, rehydrated potatoes, carrots, beef, tomatoes, potato starch, green beans, beef fat, barley, salt, celery, caramel coloring, vegetable oil, autolyzed yeast, monosodium glutamate, hydrolyzed vegetable protein, concentrated beef stock, natural flavoring, citric acid, paprika oleoresin, and garlic powder. Although we know what most of these ingredients are; what is hydrolyzed vegetable protein and others? Today food processing chemistry alludes most consumers.

The value of food additives depends on who is speaking. Those who use additives in highly processed and manufactured foods tout the worthwhile benefits to the consumer. However, others outside the food industry often paint a different pictures saying that most additives are there to increase profits and allow processed food to have an extra long shelf life. If by chance the consumer is adversely affected by the additives, caveat emptor (Let the buyer beware!)

Additives are not a new technology that has sprung up in the 1970's and 80's. During the early 1930's in London a group of health advocates described some of the commonest ways food of poor or questionable quality, low eye-appeal, and stale foods was "adulterated" (changed by the addition of additives). Milk was skimmed then water, rice and boric acid were added to give it a whiter hue. Butter might simply be white animal fat colored with a yellow dye. Salicylic acid (aspirin contains this) was added to canned meats, bacon, sausage, and other smoked meats to overcome any off flavors or odors. Formaldehyde (a chemical used in embalming) was sprayed on fish and poultry to keep it from putrefying (rotting). None of these additives were listed or even widely acknowledged as being used in foods.

At least today most products we purchase (fresh vegetables, meats, and seafood being the exception) are labeled. Have you read any good labels lately? Grab any processed food package and attempt to read the ingredients list. Reading a book written in Mandarin Chinese would be easier.

The ingredients listings are frequently written in small type and printed on a background that make them almost impossible to read. If you are able to read them, you may be confronted with meaningless names and jargon that only a food chemist or scientist could pronounce let alone understand.

Conservatively, there are over 3,000 chemicals added to the food that the average American consumer sees in the supermarket. None of them add any nutritional value to food. If they don't add to the nutritional value of the food, why are they included? Simply stated, these additives make food long-lasting, tastier, easier and cheaper to manufacture, better looking, and more uniform in appearance and color.

After each additive listed on a label there is sometime an explanation written in parentheses. For example, sulphur dioxide is "for color retention," or BHT is "an antioxidant." These additives actually keep food from deteriorating naturally. This ensures that food will stay on the shelf or in the ever-present vending machine long enough for it to be sold, no matter how long a time it takes. In a sense the life span of food is artificially extended many months beyond the norm by the extensive use of additives.

The food processing industry often starts out with real food, for example, the potato, and denatures (makes drastic change in its form or appearance) it so much that additives must be used to replace natural colors, flavors, aromas, textures, and consistency lost by processing. The use of additives allows processors to use foods of lower quality and cost to produce a product that appears to be of higher quality. Even totally artificial "foods," processed food that looks like the real thing can be created with a mix of dry protein, a liquid, and additives (Figure 4).

There is a special category of additive-rich food called fabricated foods. The space program has accelerated the creation of this new class of food. Since the space environment has limited storage space, requires food be eaten under weightless conditions, puts constraints on food preparation, restricts the availability of cooking and refrigeration equipment, as well as limiting weight and space, ordinary Earth food does not meet the astronaut's needs.

So special highly processed food has been developed. These special foods have a special additive, radiation. The foods are irradiated with X-rays so that all bacteria and mold is killed. This permits food to be fresh despite extended periods without refrigeration. The food is dehydrated so that it weighs less and takes up less space. It has to be reconstituted with water and kneaded in a small tube which is squeezed into the mouth like a tube of toothpaste.

As the space program has progressed the need for more palatable food—food that looked and tasted more like food on Earth—became apparent. One of these foods is an artificial egg. Since its development for the space program, the artificial egg has found its way into your local restaurant, delicatessen, hospital tray, and vending machine.

What first appears to be "hard-boiled egg slices" on your salad or in your sandwich is really vegetable oil, milk solids, emulsifiers, humectants, vitamins and pectin. This "yolk" is surrounded by an equally artificial "egg white" fabricated from pasteurized milk solids and a plasticizer. The whole thing is frozen then sliced into circular "egg" slices.

The space traveler may finish off a meal with freeze-dried ice cream. This ice cream is a popular item here on Earth where it may be purchased at the National Air and Space Museum in Washington, D.C., as well as in stores

that serve backpackers and campers. This ice cream is not frozen and it isn't even cold. This confection is made from real ice cream with all the water removed and stabilizing additives mixed in insure a long shelf life.

Another fabricated food is surimi which has been part of the Japanese diet for hundreds of years. Surimi is made from cheap fishes, such as sea eel, shark and croaker. It may be minced and formed into a variety of items—fish cakes, fish balls, and other food analogs—that are baked, fried, broiled or steamed.

In its traditional Japanese form, surimi is a legitimate and wise use of fish protein and other nutrients to provide a diet that is more varied. But the food technologists in the United States have taken the idea and expanded upon it.

The United States variety of surimi also starts with cheap fish, but there the similarities end. The fish is mechanically deboned, then washed with water to produce an odorless, colorless, and tasteless substance. This mass is drained of all liquid, strained and pureed to form a paste. Then sugar, salt, potassium sorbate, sodium glutamate, starch, egg whites, binders, and artificial flavors and colors are added.

The result is a product that can be shaped into a variety of seafood "delicacies." Sea Legs™ is the term to describe small pieces of this special highly processed surimi. It may also be molded into the shape of Alaskan King crab legs or even shrimp. With the addition of some streaky artificial red coloring it looks very much like the real thing.

The Food and Drug Administration describes this product as "generally wholesome . . . although the severe washing . . . results in a product that is nutritionally inferior not only to the original fish from which it was made but also to the seafood it imitates." Surimi does not contain bacteria or other pathogens sometimes found in fresh seafood, however, it does contain massive quantities of food additives. The label on the frozen or canned surimi does not tell the whole story. The FDA has allowed this product to use an alternative to the word "imitation." Use of vague names like "seafood," or "Sea Legs™," is permitted further muddling the issue. So with your cheap fish you are receiving a cocktail of chemical additives as well.

You might begin to think that all food additives are bad, or at least suspect. Not so. Food additives allow us to eat a wide variety of untainted, tasty, and attractive food which is available all year-round. Since Biblical times, with its famines caused by food shortages often due to spoilage, humankind has zealously sought methods to ensure an adequate and steady food supply. The problem is that food additives are often used and not always listed as an ingredient. The consumer needs to know what they are buying when they purchase additive laced food.

To assist you in making reasonable and healthy food choices let's run through some of the common food additives and discuss their function. This will serve as an additive atlas to help you identify what type of additives are in processed foods. (You'll want to look for these on ingredient labels). The following is excerpted from the GRAS (Generally Recognized As Safe) list, 1978 version, produced by the FDA (Federal Drug Administration).

Antioxidants—To prevent natural deterioration, such as raisins going from sweet to sour. Examples: tocopherol (vitamin E), ascorbic acid (vitamin C), butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl, octyly, and dodecyl esters, and erythorbic acid.

Preservatives—To reduce spoilage. Examples: benzoic acid, sodium benzoate, sulfites and bisulfites, potassium bromide, sulfur dioxide, calcium and sodium propionate, and sodium nitrite.

Thickeners and Stabilizers—To keep food made up of a solid and a liquid in suspension from separating. These are used extensively in prepared salad dressings and peanut butter. They keep ice cream smooth and free from ice crystals, toothpaste gels from losing moisture, and help to stabilize aerosol whipped cream. Examples—gum arabic, gum tracaganth, alginate, carageenan, pectin, guar, locust bean, amylopectin, methyl cellulose, sodium caseinate, and CMC (sodium carboxymethyl cellulose).

Humefactants—To moisten food by the retention of natural juices or added water. Polyphosphate solutions are injected, mixed, or beaten into meats (ham, poultry, and fish). The self-basting Thanksgiving turkey is given a healthy injection of a saline (salt, phosphate, and water) solution.

Enzymes—To tenderize meats, breakdown starches, degrease bones, remove bleaches, ferment lactose, and clear fruit juices. Examples—Microbial enzymes such as lactobacillus acidophyllus. (This is found in Acidophilus milk for those who have difficulty in digesting the lactose in whole milk.)

Bleaches—To remove the natural color from a food so that an artificial color may be added. To bleach flour, rice, and other cereal grains. Maraschino cherries, fruits, baking flour, and vegetable oils are all bleached with hydrogen or nitrogen peroxide and chlorine dioxide.

Acids and Alkalis—To help cheese coagulate (change from a liquid to a semisolid); as a preservative to remove excessive acidity or basicity. Some

FIGURE 4
A food scientist researches food additives to determine their effects on foods.

nutrients will break down and turn into other substances (sometimes merely bad tasting, often harmful) if the pH (level of acid or base) in the food is altered. Examples—Vitamin A, B12, and C, thiamin, histidine, and tryptophan aid in stabilizing nutrients.

Many of the foregoing additives have never been tested for carcogenicity (cancer-causing potential) or their possible effect upon a fetus in the womb. Of those that were tested some were only tested "scientifically," that is, one at a time, on healthy laboratory animals fed an otherwise healthy diet. In the real world people are more likely to consume a number of different additives contemporaneously (all at the same time). The chemical composition of additives consumed may also be altered by boiling, broiling, baking, frying, or mixing in an acid or basic environment etc. Foods containing additives in the real world cannot be directly compared to the laboratory models.

Student Project

Here is an example of a typical highly processed food label. The label is on a vending machine "fruit" pie. You probably have purchased and consumed one yourself. See if you are able to identify the additive listed and what role they are playing in the fruit pie's appearance, taste, smell, texture and shelf-life.

Cherry Fruit Pie—Made with Cherries, Enriched Flour, Niacin (a "B" Vitamin) Iron (Ferrous Sulfate), Thiamine Mononitrate (B1), Riboflavin (B2), Partially Hydrogenated Vegetable Oil and/or Animal Shortening (Contains one or more of the following: Soybean Oil, Cottonseed Oil, Palm Oil, Beef Fat, Lard), Sugar, Corn Syrup, Modified Food Starch, Skim Milk, Salt, Corn Starch, Calcium Sulfate, Citric Acid, Agar, Locust Bean Gum, Sodium Phosphate, Mono-and Diglycerides, Natural and Artificial Flavors, Artificial Colors (FD&C Yellow No. 5); Sodium Benzoate and Propionate (to retard spoilage).

Make a survey of ten vending machine foods available in your school. List all the additives you can find and note their intended purpose. Remember the ingredients list is required by law (FDA) to list the ingredients in descending order, from the ingredient weighing the most to the ones weighing least. While some food additives are listed near the end of the list they affect the food greatly because they are very potent.

Construction Activity

As we have seen, the production of food is a complex operation that involves a number of steps after the harvesting of vegetable crops or raising of livestock. A major point in the total production effort of food stuffs for human consumption and survival is access to the necessary resources for food production and the means to transport it to locations where it is needed. While North America has a very favorable climate for the production of food and the material resources for efficient production, other continents are not so fortunate.

The manned space exploration ventures may require that special means of food production be used to produce food for future space travellers. For example, extended space voyages may be of such a duration that it is impractical for a space vehicle to carry all the necessary foods for a planned excursion.

Soil-less food production may be a solution to this problem. Hydroponics is a specialized branch of agricultural production that uses any method of growing plants without soil or specially compounded soil-based composts. Other terms used to describe soil-less crop production are nutriculture, chemiculture, tank farming, and aquiculture. Figure 5 shows some potential applications of hydroponic farming.

Famines in foreign lands are frequently the result of a shortage of the necessary resources for adequate food production. Poor soil conditions, inadequate water supplies, and poor climate are major factors that contribute to insufficient food production. Each of these factors can be compensated for by the use of hydroponic food production techniques.

There are many systems that have been developed for the soil-less production of vegetable and ornamental crops. However, most all of these can be grouped under four major headings. These include water or solution culture, sand culture, aggregate culture, and miscellaneous cultural techniques.

In the activity that follows we shall experiment with the water or solution

WAYS HYDROPONICS MAY BE USED

Space colonies/space travel	Commercial growing
Desert reclamation	Famine relief
Military supplies	Materials of strategic value
Cultivation in arid or polar regions	Botanical investigations
Work for handicapped persons	Home gardening
	Elementary and secondary education

FIGURE 5
Uses of Hydroponics

technique to produce a crop. It should be remembered that the theory and practice of hydroponics are based on plant physiology, chemistry, horticulture, agronomy, and a controlled environment. You may wish to check with local produce distributors to locate a commercial hydroponic production facility. Many metropolitan markets are supplied with fresh tomatoes that are produced hydroponically.

Designing A Hydroponica

There are several factors that should be considered as we design a hydroponic growing facility. These include the type of plants to be grown, growing media, nutrient solution, and the environmental conditions (temperature, sun light, humidity, and ventilation). Table 1 shows a number of plant varieties that are suitable for hydroponic production.

A cross-section of a typical hydroponica is shown in Figure 6. The tray can be constructed of ¼" acrylic sheet and cemented together so that it is watertight. An aquarium pump can be used for aeration of the nutrient solution. A wooden frame covered with plastic screen (⅛" × ⅛" mesh, such as used for needlepoint work) for supporting the plants should be fitted into the tray. A 1½" layer of quartz gravel, such as used in aquariums is placed on top of the wire mesh for plant support. A 1" layer of wood shavings or peat moss is placed on top of the quartz rock substrate to reduce evaporation of the nutrient solution and provide additional support for the crown of the plants.

While there are a number of formulas that can be used for nutrient solutions, most will contain various weights of potassium nitrate, ammomium sulphate, monocalcium phosphate, magnesium sulphate, calcium sulphate, and other mineral salts dissolved in water. For this activity, it is suggested that a formula similar to the one shown in Table 2 be used.

With some experimentation, commercially prepared water-soluble fertilizers can be used such as Stern's Miracle Grow™ and others. When preparing nutrient solutions, use caution in handling fertilizer solutions in a safe manner as with other caustic chemicals.

Experimentation Procedures

Experimenting with food production differs substantially as compared to other activities we see in technology education programs. Traditionally, experiments and constructional activities are completed is a relatively short period of time. This experimental activity requires sufficient time to complete a growing cycle of a living plant. The four phases that we are concerned with are:

- Constructing the hydroponica and preparing nutrient solutions
- Germinating seeds and transplanting
- Daily maintenance of the hydroponica (checking nutrient levels and misting the plants)
- Harvesting the produce

The hydroponica described in this experiment is frequently called "gravel culture" because gravel or quartz rock is used to support the root system of the plant. The hydroponica can be similar to the one described here or can be one that can be designed by competing teams

CROP	GERMINATION (in days)	GROWTH (in days)	MAXIMUM pH
String Beans	7–12	70–90	6.0—6.5
Broccoli	6–12	60–80†	6.5
Cabbage	6–12	90–125†	7.5
Celery	17–23	120–150	7.5
Cucumber	5–12	55–70	6.5
Lettuces	7–12	45–60	7.5
Radishes	5–8	25–35	6.5
Spinach	8–14	40–50	6.5
Tomatoes	6–12	90–120	6.0

†From plants

TABLE 1
Some plants suitable for hydroponic cultivation and their germination rates.

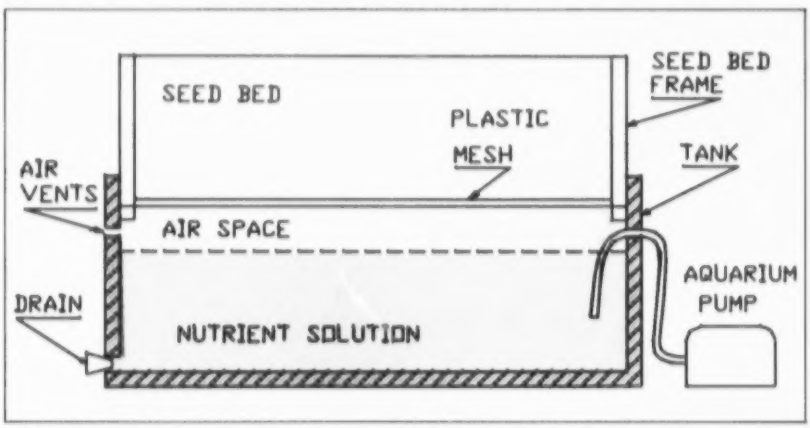


FIGURE 6
This figure illustrates the proper set-up for a hydroponica.

CHEMICAL	QUANTITY
Monobasic Potassium Phosphate	0.5 ounces
Potassium Nitrate	2.0 ounces
Calcium Nitrate	3.0 ounces
Magnesium Sulfate	1.5 ounces
Iron Sulfate	1 teaspoon
Water†	1 gallon

†Make concentrate. Dilute 1:25 (One part concentrate to 25 parts water.

TABLE 2
Suggested experimental nutrient formula for hydroponic cultivation.
Adapted from: Vegetable Gardening, Progressive Farmer/Southern Living, 1971). Check with your chemistry instructor or consult a local pharmacist for help in obtaining these chemicals.

of "hydroponic horticulturalists."

A hydroponic design can be as simple as a small flower pot suspended in a glass jar that contains the nutrient solution. The critical design factors are adequate support of the plant, capability to maintain nutrient concentrations and levels, aeration of the nutrient solution, and an air-space between the nutrient solution and the plant.

Recommended Steps

1. Select a plant variety such as radishes or leaf plants.
2. Germinate seeds in a sand plant bed.
3. Prepare nutrient solution. Mix 1 part concentrate to 25 parts water.
4. Transplant healthy plants to the hydroponica.
5. Adjust nutrient level in tank to the bottom of the plastic screen assembly.
6. Aerate nutrient solution daily. Use an aquarium pump or a bicycle pump.
7. As plant roots extend into the nutrient solution adjust the level so as to provide a 1" air space between the solution and the plastic screen assembly.
8. Change nutrient solution weekly to maintain a consistent nutrient concentration.
9. Provide adequate sunlight and temperature for individual plant varieties.

Typical Problems

Hydroponic food production is a rather exact science. This means that you are growing plants in a controlled environment and all factors must be accurately maintained. Temperature, sunlight, nutrient composition, concentration, and pH. Professional hydroponists indicate that nutrient pH, maintaining iron in the nutrient solution, inadequate sunlight, and too low a humidity are major problems in hydroponic production.

Examining individual leaves of plants can reveal plant deficiencies. For example, leaves that have a yellowish cast to them may indicate low iron levels in the nutrient solution. Similar effects are caused by a pH that is too acid. Leaves that exhibit a curled appearance usually are suffering from too rich nutrient concentration. This can be caused by improper preparation or increasing concentration of the nutrient because of water evaporation. Leaves that appear to be burned or dried around the edges can result from excessive temperature, low humidity, and or sunlight also.

Summary

Food is an important ingredient to the continued development of societies. Complex processes and operations are required to produce our foods. Today, increased uses of chemicals and artificial additives are required because of increased demands. In the future additional experimental methods will be used to produce our food products. Biotechnology and soil-less production will find increased usage. All of these methods will be required to support increasingly larger world population.

Student Quiz

1. What percentage of the total food resources are consumed by the United States? What percentage of Americans are farmers?
2. What term is used to describe the gathering of food resources?
3. What is meant by the synthetic production of food?
4. How is biotechnology applied to the production of food?
5. Take one food product and describe its processing using the following processing terms: reduction in size, separation, combining, conditioning, and forming.
6. Describe or define the term hydroponics.
7. What is the purpose of a nutrient solution in a hydroponica?
8. List or describe three applications where hydroponic food production would be beneficial.
9. Name a food additive that prevents food from deteriorating naturally.
Antioxidant
10. Name the branch of the Federal government oversees the food processing industry.
FDA—Food and Drug Administration
11. Name two common additives used to reduce spoilage.
Benzoic acid, sodium benzoate, potassium bromide, sodium nitrite
12. Name two processed foods used in the U.S. space program.
Artificial eggs, freeze-dried ice cream
13. True or False? Food additives are always listed on the ingredients list of processed food.
False
14. True or False? Sea Legs™ is a name applied to surimi-based food analogs.
True
15. True or False? Besides helping the body use food, vitamins are also used to prevent food deterioration.
True

Possible Student Outcomes

1. Synthesize how food products are obtained for human consumption.
2. Explain the following terms in relation the processing of food products: reduction in size, separation, combining, conditioning, and forming.
3. Identify foods that contain additives.
4. Synthesize both the benefits and risks associated with the use of food additives in processed food.
5. Experiment with the production of food crops.

Bibliography

Dadd, D.L. (1984). *Nontoxic and Natural*. Los Angeles: Houghton Mifflin.

Douglas, J.S. (1976). *Advanced Guide to Hydroponics*. New York: Drake.

Griggs, B. (1986). *The food factor: why we are what we eat*. London: Viking Press.

Whelan, E. & Stare, F. (1975). *Panic in the pantry*. New York: Atheneum.

Vegetable gardening. (1971) Birmingham, AL: Progressive Farmer/Southern Living.

Acknowledgments

Photographs 1 and 3—Hormel Incorporated

Photographs 2 and 4—USDA, Science and Education Administration

1988–89
BOARD OF DIRECTORS
International Technology
Education Association

President
Richard P. Bray

President-Elect
Donald P. Lauda, DTE

Past President
Jane M. Smink

Director, Region 1
John Monroe

Director, Region 2
Ronald P. Yuill, DTE

Director, Region 3
P. Thomas Ryerson

Director, Region 4
Kim B. Durfee

Director, CTEA
Russell L. Gerber

Director, CTTE
R. Thomas Wright

Director, ITEA, CS
Jerry P. Balistreri

Director, TECA
Janet Robb

Director, TECC
John H. Lucy

Executive Director
Kendall N. Starkweather

Additional materials from ITEA are available to help in the areas of:

- Project activities and development
- Curriculum development and implementation
- Professional development
- Implementing Technology Education programs

For a complete list of current titles and videos, write:

Publications Department
International Technology Education Association
1914 Association Drive
Reston, VA 22091-1502
703/860-2100

INTERNATIONAL TECHNOLOGY EDUCATION ASSOCIATION
1914 ASSOCIATION DRIVE
RESTON, VA 22091-1502